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Resource and Climate Protection through integrated Waste Management Projects in Emerging Economies and Developing Countries – Example India

Final Report

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Resource and Climate Protection through integrated Waste Management Projects in Emerging Economies and Developing Countries – Example India

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by

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Abstract

This study presents the greenhouse gas (GHG) mitigation potential through integrated waste management in emerging economies and developing countries (E+D countries) on the example of India. 3 specific cities are selected based on prioritized criteria. Bangalore, Bhopal and Haridwar are chosen from a city short list clustered by population size. GHG balances are elaborated applying the Life Cycle Assessment (LCA) method for waste management. For each balance the respective status quo is determined and compared with two developed, best possible realistic optimization scenarios. Because data was not available on a central level, the necessary data had to be derived through secondary data, site visits as well as expert interviews and completed by assumptions.

The GHG results for the 3 cities demonstrate the significant GHG mitigation potential which derives from diversion from landfill. Although, the GHG results are inaccurate due to the difficult data situation, at least the order of magnitude for this GHG mitigation is robust. In addition, the scenarios show the possibilities of climate protection through integrated waste management, and extrapolation of specific results reveals that the potential contribution of small cities to the national GHG mitigation of the waste sector is relevant and should be considered.

The study's most important conclusions are that though the challenges for Indian cities are high, in general, India is on the right track with rules and regulations as well as programs supporting ULBs at least partly financially. However, some major obstacles need to be addressed with the most relevant being the establishment of a data collection and monitoring system for MSW which is not only prerequisite to implement proper waste management but is also required for Nationally Appropriate Mitigation Actions (NAMAs) and Nationally Determined Contributions (NDCs).

Kurzbeschreibung

Die Studie beschreibt das Treibhausgas-Minderungspotenzial durch integrierte Abfallwirtschaft in Schwellen- und Entwicklungsländern (E + D-Länder) am Beispiel Indiens. Anhand von priorisierten Kriterien werden 3 spezifische Städte ausgewählt. Basierend auf einer nach Bevölkerungsgröße gruppierten Städtekurzliste sind dies Bangalore, Bhopal und Haridwar. Treibhausgasbilanzen werden nach der Ökobilanzmethode für die Abfallwirtschaft erstellt. Für jede Bilanz wird der jeweilige Status quo ermittelt und mit zwei entwickelten, möglichst realistischen Optimierungsszenarien verglichen. Da Daten auf zentraler Ebene nicht verfügbar waren, mussten die notwendigen Daten durch Sekundärdaten, Standortbesuche sowie Experteninterviews abgeleitet und um Annahmen ergänzt werden.

Die THG-Ergebnisse für die drei Städte zeigen das signifikante Treibhausgas-Minderungspotenzial, das sich durch die Abkehr von der Deponierung ergibt. Obwohl die THG-Ergebnisse aufgrund der schwierigen Datenlage ungenau sind, ist zumindest die Größenordnung der THG-Minderung robust. Darüber hinaus zeigen die Szenarien den möglichen Klimaschutzbeitrag durch integrierte Abfallwirtschaft, und die Extrapolation spezifischer Ergebnisse zeigt, dass der potenzielle Beitrag von kleineren Städten zur nationalen THG-Minderung durch den Abfallsektor relevant ist und berücksichtigt werden sollte.

Die wichtigsten Schlussfolgerungen der Studie lauten, dass Indien trotz der großen Herausforderungen für indische Städte mit den rechtlichen Vorgaben und Programmen, die Kommunen zumindest teilweise finanziell unterstützen, im Allgemeinen auf dem richtigen Weg ist. Wichtige Hindernisse müssen jedoch angegangen werden, wie v.a. die Einrichtung eines Systems zur Datenerfassung und -überwachung für Siedlungsabfälle, das nicht nur Voraussetzung für die Durchführung einer ordnungsgemäßen Abfallwirtschaft ist, sondern auch für NAMAs („national angemessene Minderungsmaßnahme“) oder NDCs („national festgelegte Beiträge“) erforderlich ist.

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List of Abbrevations

AMRUT	Atal Mission for Rejuvenation and Urban Transformation (second phase of JNNURM; newly launched by the GoI for 500 cities with focus on ensuring basic infrastructure services)
BAU	Business as usual
BBMP	Bruhat Bangalore Mahanagara Palike ("Bangalore Municipal Corporation")
BDA	Bangalore Development Authority
BEL	Bharat Electronics Limited
BHEL	Bharat Heavy Electricals Limited (http://www.bhel.com/)
BMC	Bhopal Municipal Corporation
BR	Bienniel Report (Annex I Parties; UNFCCC; Kyoto-Protocol)
BUR	Bienniel Update Report (Non-Annex I Parties; UNFCCC; Kyoto Protocol)
C&DW	Construction & demolition waste
CCAC	Climate and Clean Air Coalition
CDM	Clean Development Mechanism (Kyoto-Protocol)
CHP	Combined heat and power plant
CPCB	Central Pollution Control Board (India, national level)
CPHEEO	Central Public Health & Environmental Engineering Organization (India, national level)
CRF	Common Reporting Format (Kyoto-Protocol)
CW	Commercial waste
D2D	door-to-door
DOC	Degradable organic carbon
DOCf	DOC which decomposes
E+D-countries	Emerging economies and developing countries
ENVIS Centres	Environmental Information System Centres (28 centres mandated to develop a distributed network of subject-specific databases)
EW	E-waste
GCF	Green Climate Fund
GDP	Gross domestic product
GHG	Greenhouse Gas
GNI	Gross national income
GoI	Government of India
GPW	Garden & park waste
GW	Garden waste
GWP	Global Warming Potential
HHW	Household and similar waste

HW	Hazardous waste
IFAT	"World's Leading Trade Fair for Water, Sewage, Waste and Raw Materials Management"
IGCS	Indo-German Centre for Sustainability (inaugurated Dec 2010 at the IIT Madras, Chennai; with Waste Management as one of six main research areas; http://www.igcs-chennai.org/)
IISC	Indian Institute of Science
IIT	Indian Institute of Technology
INDC	Intended Nationally Determined Contribution (submitted to UNFCCC)
IPCC	Intergovernmental Panel on Climate Change
IPMA	Indian Paper Manufacturers Association (http://www.ipma.co.in/)
ISAH	Institute for Sanitary Engineering and Waste Management, University Hannover Germany
IW	Industrial waste
JNNURM	Jaharwalal Nehru National Urban Renewal Mission (India)
JWG	Joint Working Group
KMC	Karnataka Municipal Corporation
LFG	Landfill gas
MBT	mechanical-biological treatment
MBS	mechanical-biological stabilization
MCF	Methane correction factor
MNRE	Ministry of New and Renewable Energy (India)
MoEF	Ministry of Environment, Forest and Climate Change (India, also MoEFCC)
MoUD	Ministry of Urban Development (India; in 2017 renamed in Ministry of Housing and Urban Affairs, MoHUA)
MRF	Material recycling facility
MRV	Monitoring, reporting, verification
MSW	Municipal Solid Waste
MSWI	Municipal solid waste incinerator
NAMA	Nationally Appropriate Mitigation Action (Kyoto-Protocol)
NC	National Communication (to the UNFCCC under the Kyoto-Protocol)
NEERI	National Environmental Engineering Research Institute (India)
NDC	Nationally Determined Contribution
NIR	National Inventory Report
NSWAI	National Solid Waste Association (Indian ENVIS Centre)
OECD	Organisation for Economic Co-operation and Development
OX	Oxidation factor

RDF	Refuse derived fuel
SBM	Swachh Bharat Mission
SLF	Sanitary landfill
SPCB/PCC	State Pollution Control Board / Pollution Control Committee
SWM	Solid waste management
SWDS	Solid waste disposal site
TMP	Thermochemical Pulp
TPD	Tons per day
ULB	Urban Local Body
UNFCCC	United Nations Framework Convention on Climate Change
WtE	Waste to Energy

Summary

The relevance of integrated waste management for resource and climate protection is demonstrated in several studies. Both in industrial as well as in emerging economies and developing (E+D-) countries the waste sector can contribute considerably to greenhouse gas (GHG) mitigation. Studies commissioned by the German Environment Agency (Dehoust et al. 2010, Vogt et al. 2015) revealed the achievable contribution to climate protection which especially results from diversion from landfill. In many countries, not only but most of all E+D-countries, disposal of municipal solid waste (MSW) is still dominating waste management practices, partly under unsanitary conditions. Efforts to improve the situation and to implement an integrated waste management system can both contribute to minimize impacts on human health and the environment as well as to climate protection. Especially diversion from landfill and thus altogether avoiding methane emissions from disposed of waste is a major driver for GHG mitigation in the waste sector.

The objective of the study 'Resource and Climate Protection through Integrated Waste Management Projects on the example of India' is to support decision-makers in identifying the potential to reduce GHG emissions in the Solid Waste Management (SWM) sector in order to plan their waste management or e.g. Nationally Appropriate Mitigation Actions (NAMAs) and Nationally Determined Contributions (NDCs) accordingly. Ultimately, the project aims to indicate if/how the LCA approach in waste management (decision-making aid) can be connected to reporting requirements in line with UNFCCC, which are assumed to be required for monitoring, reporting, verification (MRV) of Waste-NAMAs, NDCs and others.

On the example of India the study refers to 3 specific cities, which are selected on the one hand based on information on India and, to some extent, at federal state or local level, and on the other hand based on prioritized selection criteria like especially stakeholder interest, contacts to actors, availability of data and population size and density. From a short list of cities subdivided into three clusters depending on the population size the following cities are selected:

- Bangalore from the cluster of cities with > 3 million inhabitants
- Bhopal from the cluster of cities with >1 to 3 million inhabitants
- Haridwar from the cluster of cities with 0.1 to 1 million inhabitants

In a rough approximation the selected 3 cities can also be used as proxy for city size clusters, and extrapolating the results can give a rough idea of the national dimension of GHG mitigation scenarios.

Prior to the data collection phase a comprehensive data template was established to enable systematic interviews and also receive information on data gaps and reliability of data. The initial data collection phase in Bangalore revealed that most important and critical data is not available at a central level, but dispersed at many and various levels. High population growth and migration into cities as well as the rapid change in life style confronts municipalities with an increase of waste generation and change in composition. It is challenging for most municipalities in India to keep up with these dynamic changes in their urban perimeter. So, data collection and management is often of secondary concern for the public sector authorities. The necessity for primary data collection from such a multitude of disperse, local sources had not been predictable and exceeded the research scope and design considerably. The project is therefore based on available secondary level data research, and the efforts to derive first-hand information through site visits and expert interviews were enhanced. Additionally, workshops in Bangalore and Haridwar – initially meant to discuss optimization scenarios – were readdressed to verify collected data and potentially close data gaps.

General background information for India derived from studies provides the following picture: The per capita waste generation in Indian cities is estimated to range from 0.17 to 0.54 kg/cap/day in

small towns (< 1 million inhabitants) and from 0.22 to 0.62 kg/cap/day in large cities (> 2 million inhabitants) (Kumar et al. 2009, 2017). For 2011, the collection rate was reported to be 70% and the treatment rate about 13% of the waste generated (Joshi & Ahmed 2016). According to Kumar et al. (2017) the informal sector has a key role in extracting value from waste, but approximately more than 90% of residual waste in India is dumped in an uncontrolled manner.

The regulatory framework as well as a MSW manual have been prepared and implemented by nodal ministries in 2000 (MSW Rules 2000, MoEF 2000; MSW Manual, MoUD/CPHEEO 2000). However, the responsible municipal authorities (Urban Local Bodies - ULBs) could not fully comply with the guidelines. ULBs often lacked information about advantages and disadvantages of technologies, on how to implement integrated SWM systems as well as on costs or environmental and social impacts. In addition, budget constraints and lack of capacity in executing solid waste management projects could also be reasons for some non-compliance. The revised versions, the “MSW Manual 2016” (MoUD 2016) and the “SWM Rules 2016” (MoEF 2016) considered the above mentioned deficiencies and aimed for more comprehensive guidelines and regulations. For example, the MSW Manual 2016 provides a seven-step approach for developing a municipal solid waste management plan in ULBs, including a gap analysis of the current status with detailed information on data collection methodologies to derive representative data on waste quantities and composition. Salient features of the SWM Rules 2016 are for example the extension of the scope beyond the municipal perimeters, the duty for source segregation put on waste generators, the responsibilities of local authorities with regard to waste collection, and the provision to establish a comprehensive monitoring system.

The financial situation was also improved through several programs which have been launched to support ULBs, like the national programs Swachh Bharat Mission (Clean India Mission), the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and its follow-up program AMRUT (Atal Mission for Rejuvenation and Urban Transformation) or the Smart Cities Program. However, not all cities benefit from these funds and partly funding is not sufficient. Financing is still needed and may be provided through user fees for solid waste management (SWM Rules) or for example by funding of NAMAs for the waste sector.

Facts and findings of SWM systems in the 3 selected cities

Bangalore, located in southern India, is the capital of the state Karnataka. It is an important commercial center with some of the major, especially IT based industrial establishments. Bangalore has the reputation of being one of the fastest growing cities in Asia. Its population was about 8.5 million inhabitants as per Census of India 2011, and is likely to be 10 million inhabitants by 2021. The city is structured into 198 wards in 8 sub-administrative zones. The municipal authority is called Bruhat Bangalore Mahanagara Palike (BBMP). MSW is handled by the SWM Department which is responsible for MSW from households. So-called bulk generators like trade and commerce, hotels, canteens, apartment and high-rise blocks are required to manage their waste either in-situ or to contract BBMP authorized private service providers (KSPCB 2014). In addition, like in general in India, recyclable waste is basically processed by the informal sector. The respective amounts of both, bulk generators and informal recycling, are assumed to be relevant though data are not available.

Data on MSW generated, available from studies or from BBMP, vary between 3,000 and 4,000 TPD (BBMP 2016b, TERI 2015, KSPCB 2014). Data on waste composition are not available on a representative basis. Although, a study for the West Zone (Weichgrebe et al. 2016) provides the waste composition from a comprehensive analysis it is not applicable to other zones in Bangalore. The waste composition available from BBMP (2016a) is an approximation for guidance only. However, the latter was used for the GHG calculations in lack of better data.

Waste collection is provided by BBMP on a daily basis. Waste is collected by door-to-door (D2D) collection from households and collection from litter spots. Bins/litter bins are only used in the commercial areas. Although, the collection coverage is 100%, approximately 20% of the waste generated is not collected. BBMP has emphasized segregation at source. In general, 3 categories of waste are destined for source segregation: wet, dry and sanitary waste. As of the data collection phase in 2016 this source segregation was hardly implemented. Dry waste contained non-recyclables or low quality material. Wet waste – defined as biodegradable waste – consisted of a mixture of non-segregated dry waste, textiles, biodegradable waste and sanitary waste, and is therefore denoted as "wet/mixed waste" in this study.

Dry waste is brought to Dry Waste Collection Centers (DWCC), while wet/mixed waste is taken to one of 10 mechanical-biological treatment plants (MBTs). In both cases considerable amounts were not accepted or not processed due to low quality (DWCC) or lack of capacity/non-operation (MBTs). At the time of the visit in Bangalore, in October 2016, 7 of the 10 plants were not operating. Reasons were blockades from protesting citizens, power cut-off due to not paid bills, a RDF storage fire and problems with the delivered wet/mixed waste which consists of long rope-like textile material that regularly clogged the trommels and prevented proper separation of a RDF and an organic waste fraction, resulting in poor quality products (RDF, compost) which are not and/or hardly marketable. The mass flows of the treatment processes are assessed based on interview outcomes, literature and expertise:

DWCC: 30% not accepted; sorted recyclables output 80% of input and 20% residues.

MBT: 10% not processed; output: 20% RDF, 20% compost, 15% stabilized solid residues, 10% inert, 35% losses (water, degraded organics).

From all outputs only sorted recyclables are attributed with a benefit in the GHG calculation. This also accounts for a small amount of source segregated food waste which is treated in small-scale biomethanation plants. In October 2016 only 4 of 16 plants were operational. The concept is simple with a rather low, not self-sustaining biogas yield, and digestate which is stored in a slurry tank is ultimately drained to the water bodies. Thus this concept is not very climate- or environmentally friendly. The not accepted and not processed waste as well as rejects, impurities and low quality RDF are basically stored and/or disposed of at dump yards and uncontrolled dumps or quarries. At least two of the officially closed disposal sites are higher than 15 m. This information is relevant for the GHG calculation because in lack of regional data default values provided from the Intergovernmental Panel on Climate Change (IPCC 2006) are used to calculate methane emissions from disposal which depend on the height of the landfill body.

Bhopal, located in central India, is the capitol of the state Madhya Pradesh. As per Census of India 2011, the population of Bhopal was about 1.8 million. A significant proportion (about 27%) of the population lives in the 388 slum areas across the city (Smart Cities Projects 2015). The city is structured into 85 wards in 19 zones, and is administered by the Bhopal Municipal Corporation (BMC). SWM is generally the responsibility of BMC. However, also several NGOs and Self-Help-Groups are involved in waste management. Bhopal's informal sector includes more than 8,000 recyclers, where BMC employs more than 4,700 personnel for SWM (CDIA 2015).

Data on MSW generated available from studies vary between 700 and 800 TPD (Sharma 2016, Katiyar et al. 2013, Dasgupta 2016). Data on waste composition are available from BMC (2006) and from a study for 2009 (Katiyar et al. 2013). The more recent was used for GHG calculations though also outdated.

Waste collection is well implemented by the BMC Health Department (Sharma 2016). But to date MSW from households and commercial centers is usually unsegregated when collected. The waste collected is unloaded at one of the more than 3,000 collection bins/centers and then transported to the Bhanpura dumpsite (CDIA 2015). The Bhanpura dumpsite is in use for over 35 years, is meanwhile lying inside municipal limits and has reached its capacity (BMC 2014). Delivered MSW is weighed before disposal and approximately since 2016 digitally recorded. The dumped waste is piled up not higher than 5 m – and thus considered shallow regarding IPCC (2006) – and is neither compacted nor covered. Some other activities in Bhopal like small-scale composting units or a biomethanation plant (actually in a much better state than those in Bangalore) operated by Self Help Groups or NGOs, informal plastics recycling or the attempt to produce fertilizer from dumped waste which is digged out and mechanically treated in a plant next to the landfill are not considered in the GHG calculation as either very specific or no data on city level is available.

Haridwar, located in the North Indian state Uttarakhand at the Ganga river, is one of the seven sacred cities of Hindu culture. As per Census of India 2011 Haridwar city has a population of about 230,000 people. However, the city's floating population (tourist, worshippers) is up to about 160,000 people per day (IPE 2009, CPCB 2016). A considerable proportion of the population - depending on source (MoUD 2016, IPE 2009) about one quarter to one third of the permanent population – is living in slum areas. The city is divided into 30 wards, aggregated in 4 zones (CPCB 2016). The municipal authority is called Nagar Nigam Haridwar.

Data on MSW generated available from studies vary between 200 and 400 TPD (Urban Development Directorate 2015, MoEF 2015, Nagrath 2016). For the GHG calculations in this study, the average MSW generation is assumed to be 237 TPD, including an estimated waste generation of 315 TPD during 20 days per year due to religious festivities (Nagar Nigam Haridwar 2015). Data on waste composition are available from three different sources (IPE 2009, Sharma et al. 2010, Jain & Sharma 2011). Although, (IPE 2009) refers to the years 2007/2008 it was used for the GHG calculation, because it is more comprehensive than information from the other sources.

Waste collection is provided in all wards on a daily basis though the collection rate is reported to be 72% (MoUD 2016). The non-collected waste is basically scattered onto the streets or into open sewers. Especially the latter have the potential to be washed out into the Ganga river and to increase marine littering. D2D collection from households was commissioned to a private company which provided source segregated D2D collection of biodegradable and non-biodegradable waste in 22 wards in early 2017. MSW from the remaining 8 wards was still collected unsegregated by the municipality (CPCB 2016, HMC 2016 & 2017). The source segregation was started although at the time of the visit in Haridwar in March 2017 the SWM facility intended for treatment of the biodegradable waste was still under construction.

The collected waste is transported to a community container (waste storage depot) where the collectors manually extract salable recyclables. The residual waste is finally transported for disposal to the uncontrolled dumpsite at Sarai (near the SWM facility under construction). MSW is not piled up higher than 5 m and during the visit in March 2017 landfill fires were observed.

The findings and assumptions for the status quo scenarios for the 3 cities are summarized in Table 1.

Some major observations and challenges recognized from the information gathering phase are:

1. The difficult data situation: Data are not available on an aggregated level, the fate of the waste is partly not known, MSW from bulk generators and informal recycling are not within the responsibility of the municipality and not recorded on municipal level. Data on waste composition or characteristics is available from a few studies but are partly outdated and/or not representative.
2. The challenging situation of SWM: Waste collection and treatment as well as recycling are applied but relevant amounts are still not collected and disposed of in an unsanitary manner. Source segregation has generally started but MSW facilities to receive this waste were either not yet in place or not properly operating.
3. The observed administration and policy challenges: A high staff turnover as well as the lack of

capacity at municipal level makes it difficult to consistently execute waste management plans. The assignment of more responsibility to the waste generators like bulk generators helps to relieve municipalities to some extent but the lack of available data or a monitoring system for all MSW streams makes it difficult to assess or plan proper waste treatment capacities because MSW from bulk generators is likely to end up in the municipal waste stream nevertheless.

Table 1: Overview assumptions status quo scenario for the 3 cities

	Bangalore	Bhopal	Haridwar
MSW generated	4000 TPD	800 TPD	237 TPD
Collection rate	80%	100%	72%
Source segregation started	yes	no	yes
Fate of non-collected waste	90% unsanitary disposal 8% open burning 2% homecomposting	-	100% scattered
Treatment of collected MSW	25% DWCC 72.5% MBT[1)] 2.5% biomethanation	100% unsanitary disposal	100% unsanitary disposal
Main fractions waste composition:			
Organic waste (food, green waste, hay, straw, wood)	59%	69%	50%
Recyclables (paper, plastic, textiles, glass, metals)	33%	20%	23%
Inert (sand, silt, debris)	5%	10%	24%
Waste parameters for MSW generated calculated from the waste composition			
Heating value [MJ/kg]	7.6	5.8	6.3
Fossil carbon [% mass]	6.8%	3%	5.6%
Regenerative carbon [% mass]	16.4%	17.1%	13.5%

1) 10 MBTs, of these 7 were not operating in October 2016, and problems in properly separating MSW in a RDF and organic fraction resulted in hardly marketable low quality products.

SWM scenarios and GHG calculation

In the light of the data situation, the status quo scenarios as well as the optimization scenarios had to be based mostly on assumptions. In addition, some clarifications are necessary for a common understanding of terms and definitions. For example, in India the term "composting" is often used indifferent if the treatment of wet/mixed waste is addressed or of wet/source segregated organic waste. To avoid misunderstandings in this study "composting plant" is used for the treatment of source segregated wet/organic waste only and "MBT" for the treatment of wet/mixed waste. For RDF fractions from MBT different quality grades are distinguished. "Biomethanation plant" is used for small-scale plants as implemented in Bangalore, while anaerobic digestion (AD) plant is used for efficient modern low emission plants. Waste incineration is considered in the optimization scenarios in form of co-incineration in WtE plants which typically process e.g. agricultural residues and are more frequent in India than MSW incineration plants, in form of co-incineration in a "cluster WtE", a cooperation concept of several cities processing source segregated combustible waste, and in form of newly build WtE plants if the waste streams are large enough and a new plant appears to be economically viable. Incineration of generated or collected MSW is not considered because usually in India this waste has a low heating value and is not suitable for incineration.

The **development of the optimization scenarios** aims at representing integrated waste management systems with potential co-benefits for GHG mitigation. The different settlement structures of the 3 cities are considered as well as existing approaches and plans to be as realistic as possible. Also, achievable and realistic technologies are taken into account and operational conditions fit to achieve the necessary quality outputs. The potential GHG mitigation is not the maximum possible, but the realistically achievable in the nearer future. The potential share of waste for recycling, waste for composting or for incineration is based on the waste composition for MSW generated. Altogether two optimization scenarios are developed as a step by step approach, with scenario 1 as the first step to a further optimized scenario 2. **Landfill gas collection is not an option**. Basically, landfilling of non-treated usable waste is not allowed according to the SWM Rules (MoEF 2000, 2016). Although still considerable waste amounts are disposed of at unsanitary landfills, ULBs are struggling to implement compliant treatment options. In addition, existing landfills are hardly suitable for the subsequent installation of a gas collection system as they are mostly shallow and unmanaged.

The **scope of the scenarios** is focused on MSW from households in the responsibility of the municipality. Neither MSW from bulk generators nor MSW treated by the informal sector are included due to lack of sufficient data, though especially informal recycling would contribute considerably to potential GHG mitigation.

The **assumptions for the optimization scenarios** of the 3 cities are shown in Table 2. In general, 100% collection is assumed. This is the first step to an integrated waste management system. In addition, source segregation is considered as a key element to achieve proper treatment and quality products. Although, this needs educational and counseling service for the citizens as well as for the collectors, it is assumed easier to be implemented in E+D countries than technical solutions. In addition, organic waste must be collected separately and not mixed with other residual waste to prevent irreversible pollution of the organic material. Realization is surely easier in small cities as less anonymous but also possible in large/mega cities at least at less densely built-up areas.

For Bangalore and Bhopal moderate source segregation of wet/organic waste is assumed in scenario 1 which is further increased in scenario 2, though each to a higher extent for Bhopal due to its comparably high share of organic waste in the waste composition. In addition, scenario 2 assumes partial treatment of source segregated wet/organic waste in an efficient, low emission anaerobic digestion (AD) plant. For Haridwar a more pretentious segregation rate of wet/organic waste is already assumed for scenario 1 which is not further increased in scenario 2. Instead scenario 2 focuses on the prevention of marine littering by assuming a most efficient D2D collection where littering does not take place any more. Thus the silt from the open sewers is excluded from the MSW stream, less residual wet/mixed waste needs to be treated and recyclables remain unspoiled resulting in a higher recycling rate.

For Bangalore and Bhopal the assumed recycling rate is equal in scenario 1 and 2. An additional source segregation of combustibles is considered for Bhopal because the city plans to cooperate with other cities to implement a cluster WtE. For all 3 cities it is assumed that residual wet/mixed waste is mechanical-biologically treated in scenario 1 and 2. For Bangalore scenario 2b additionally examines WtE treatment of the residual wet/mixed waste fraction. The outputs from MBT are deduced respecting the waste composition of the residual waste as far as possible. For Bangalore generation of high quality RDF is assumed which can be co-incinerated in cement kilns. For Haridwar it is assumed that treatment of source segregated wet/organic waste and of residual wet/mixed waste can take place in a 2 line operation in the new SWM facility. There seems to be enough space for strictly separated treatment of the two waste streams. For Bangalore it seems most reasonable to rededicate some of the existing MBTs to the treatment of source segregated wet/organic waste only, like it was done earlier in the KCDC plant, while the remaining MBTs continue to process the residual wet/mixed waste.

Table 2: Overview assumptions for the optimization scenarios for the 3 cities

	Scenario 1	Scenario 2
Collection rate all 3 cities	100%	100%
Bangalore		
Source segregation	15% wet/organic waste 25% recyclables to recyclers	40% wet/organic waste 25% recyclables to recyclers
Residual wet/mixed waste	60%	35%
Treatment of source segregated wet/organic waste	100% composting	70% composting 30% anaerobic digestion (AD)
Treatment of residual wet/mixed waste	100% MBT, output: 20% RDF to WtE plant 15% RDF to cement kiln 30% stabilized solid residue, inert 0.3% metals 35% losses	2a) 100% MBT, output: 10% RDF to WtE plant 25% RDF to cement kiln 30% stabilized solid residue, inert 0.3% metals 35% losses 2b) 100% WtE plant
Bhopal		
Source segregation	30% wet/organic waste 20% combustibles to cluster WtE 15% recyclables to recyclers	50% wet/organic waste 20% combustibles to cluster WtE 15% recyclables to recyclers
Residual wet/mixed waste	35%	15%
Treatment of source segregated wet/organic waste	100% composting	70% composting 30% anaerobic digestion (AD)
Treatment of residual wet/mixed waste	100% MBT, output: 20% RDF to WtE plant 45% stabilized solid residue, inert 1% metals 34% losses	100% MBT, output: 30% RDF to WtE plant 40% stabilized solid residue, inert 1% metals 29% losses
Haridwar		
Source segregation	45% wet/organic waste 10% recyclables to recyclers	45% wet/organic waste 15% recyclables to recyclers 17% silt, inert excluded from MSW
Residual wet/mixed waste	45%	23%
Treatment of source segregated wet/organic waste	100% composting in new SWM facility, 2 line operation, strictly separated from wet/mixed waste	
Treatment of residual wet/mixed waste	100% mechanical/manual sorting and biological stabilization, output: 50% stabilized solid residue, inert 15% recyclables 35% losses	100% mechanical/manual sorting and biological stabilization, output: 45% stabilized solid residue, inert 20% recyclables 35% losses

"Losses" are water and mass losses which result from biological treatment through degradation and evaporation.

For the GHG calculations the Life Cycle Assessment (LCA) method in waste management is used, which is a most suitable method to aid on decision making because it reflects all GHG emissions related to the treatment of a certain amount of waste. It not only includes direct emissions but also future emissions resulting from landfilling as well as potential GHG savings in other sectors than the waste sector resulting from waste management activities like generation of energy and secondary products. The latter have the potential to substitute conventional energy and primary production. Potential GHG savings are considered as credits with negative values.

Aside from assumptions according to the mass flows, further assumptions are necessary with regard to waste characteristics. The most relevant parameters, carbon content and heating value, are calculated from the waste composition for MSW generated and are estimated for source segregated combustibles or the RDF fractions. Harmonized emission factors from Vogt et al. (2015) are used for the calculation of recycling and biological treatment. Disposal of waste is calculated using internationally accepted default values (IPCC 2006). The methane correction factor (MCF) is assumed to be 0.4 for Bhopal and Haridwar because the disposal sites are shallow. For Bangalore the MCF is set to 0.6 for uncategorized disposal sites because at least two are not shallow.

Table 3 presents the **GHG results** for the 3 cities. Due to the many assumptions which were necessary the results are to understand as rough approximations and are given in rounded values. "Debits" are the direct emissions (including future emissions), "credits" are potential GHG savings, "net" refers to the difference between debits and credits. In all status quo scenarios the debits are dominated by methane emissions from landfilling. Of the three cities only Bangalore achieves some credits for recycling. The results for the scenarios 1 and 2 clearly demonstrate the significant GHG mitigation potential which derives from diversion from landfill. Here, the regulatory and policy framework in India already provides a good basis, which is a most relevant co-benefit for climate protection.

Table 3: GHG results for the 3 cities (rounded values)

CO_2eq per year	Status quo	Scenario 1	Scenario 2	
Bangalore			a)	b)
debits in tons	640,000	380,000	310,000	330,000
credits in tons	-120,000	-690,000	-680,000	-670,000
net in tons	520,000	-310,000	-370,000	-340,000
specific net result per ton	360	-210	-250	-240
specific net result per capita	62	-37	-44	-41
Bhopal				
debits in tons	171,000	62,000	57,000	
credits in tons	0	-97,000	-108,000	
net in tons	171,000	-35,000	-51,000	
specific net result per ton	590	-120	-170	
specific net result per capita	95	-19	-28	
Haridwar				
debits in tons	29,000	11,000	11,000	
credits in tons	0	-29,000	-33,000	
net in tons	29,000	-18,000	-22,000	
specific net result per ton	340	-200	-250	
specific net result per capita	75	-45	-55	

Although, there is still some ground to cover until an integrated waste management system is completely implemented, the scenario 1 for the 3 cities could be perceived as a first step within a decent time frame. The scenario 2 for each of the 3 cities is more challenging to realize as they include a further increase of wet/source segregated organic waste for Bhopal and Bangalore, and for Haridwar the strict prevention of littering. Additionally, efficiently operated low emission AD plants are part of scenario 2, which needs not only proper input material but also higher investments. Nevertheless, both scenarios 1 and 2 are considered feasible and achievable for the Indian cities, and both already provide a significant GHG mitigation although they are not exploiting the maximum possible GHG emission reduction. Prerequisite to implement functional waste management systems is to know the waste quantities deriving from all relevant sources including bulk generators as they decide on the necessary capacities, and to know the waste properties as they decide on possible treatment routes. The latter also determine the GHG results. For example for Bangalore the two concepts distinguished in scenario 2a and 2b do not lead to very different GHG results. However, this is only true if the assumptions on the waste characteristics are reliable and the treatments applied are constructed and operated according to the state of the art of technology, e.g. yielding a quality RDF. Only then the conclusion is valid that from a climate protection point of view it does not matter which of the two concepts a city opts for.

The difference between the specific net results per capita of the status quo scenario and scenario 2 are used for the **extrapolation of the GHG results** based on the population data of the Census of India 2011 in order to get a rough idea of the national dimension of GHG mitigation scenarios for the 3 different city sizes. Altogether 468 towns & urban agglomerations are reported of these 10 have more than 3 million inhabitants (large/mega cities), 34 between 1 and 3 million (medium sized cities), and 424 between 0.1 and 1 million (small cities). The total population in the towns is identified to about 61 million in large/mega cities, to about 49 million in medium sized cities and to about 84 million in small cities. The total GHG mitigation potential for all towns is calculated to about -23.5 million tons CO_2eq per year. The share of the 3 city clusters is 28% for the large/mega cities, 26% for the medium sized cities and 47% for the small cities. Even if the contribution of the small cities is overestimated the results illustrate that the sum of smaller towns are a relevant factor for the national GHG mitigation through waste management.

However, as mentioned before the GHG results calculated in this study had to be based on many assumptions. Although the order of magnitude for the GHG mitigation through diversion from landfill is robust, the results are considered too inaccurate and nonbinding to be accepted for example by financing institutions like the NAMA facility or for NDCs. They may well be over- or underestimated. To emphasize that **waste data matters for the reliability of GHG results** specific GHG results for the most relevant treatment options are provided in this study. Especially variations for solid waste disposal reveal differences up to a factor 3 if the DOC and the conditions of disposal sites (MCF) are not known or estimated incorrectly. Also waste incineration can result both in net debits and net credits depending on the fossil carbon content, the heating value and the conventional grid electricity which is potentially substituted.

NAMAs and NDCs require MRV systems which shall comply with common international UNFCCC reporting requirements to be able to track emissions and emission reductions toward the mitigation goal (GIZ 2013). The addressed GHG inventories refer to all sectors in a national economy, and only direct and yearly emissions are reported per sector. The waste sector in the GHG inventory focuses on non-energy emissions only. Crediting GHG emissions potentially saved by waste management in other sectors is not an option in order to prevent double accounting. In comparison between the LCA method in waste management and the GHG inventory for the waste sector two aspects are fundamental antipodes: (1) landfilling of waste and (2) considering potentially avoided emissions. However, for a waste NAMA or NDCs it is very difficult for decision-makers to assess different strategies in waste management based on the GHG inventory because neither future emissions from disposal nor potential GHG savings become visible. This is only possible with the LCA method in waste management.

Therefore, it is recommended to use both methods – LCA and inventory – for decision-making and for

MRV in the waste sector. The two methods cannot be merged to a single method to deliver both decision making aid and monitoring of the economy-wide progress. Hence, it is recommended to develop and use an interface between the two methods with linkages for direct emissions which are equal for both methods, linkages for the input parameters used for solid waste disposal like DOC, DOCf, etc. and maybe a time series for the LCA results on disposal which can be easily done using IPCCs default values for the decay rate. In addition, avoided emissions could be documented and described separately for information only. The recommended approach can be easily implemented. The much more important factor for MRV is GHG data quality.

Conclusions

Increase of waste generation and change in waste composition resulting from population growth and rapid change in lifestyle impose difficulties on India and Indian cities to implement an integrated waste management system. However, in many ways India is on the right track. The national and regional programs launched support ULBs partly financially. The revised MSW Rules 2016 stipulate proper waste management and the 2016 MSW Manual aids ULBs to develop municipal solid waste management plans. In addition, there are many very good initiatives on grass root level which can be integrated in waste management planning.

Although, the GHG results cannot be absolutely accurate, at least the order of magnitude for the GHG mitigation through diversion from landfill is robust. In addition, the GHG scenarios show the possibilities of climate protection through integrated waste management. However, to achieve this some major challenges need to be addressed:

- Municipalities need to know the total waste amounts generated to plan sufficient treatment capacity. They need to establish a comprehensive data collection and monitoring system for MSW.
- The waste composition, the properties of the waste, is essential to decide on suitable treatment options. Representative sampling and analysis as proposed in the MSWM Manual 2016 are a prerequisite to implement proper waste management.
- In addition, it is strongly recommended to undertake pilot tests with collected MSW before implementing a waste treatment plant to prevent failure of technologies in operation.
- Source segregation of wet/organic waste is mandatory for quality compost. Producing quality compost does not need high-technology units but can be achieved with source segregation and good professional operation.
- In general, source segregation is seen as key to clean waste fractions allowing quality products and high recycling rates. Realization is surely easier in small cities because of their stronger social coherence, but also possible in large/mega cities at least in higher income and less densely built-up areas. Source segregation does not need high investments into equipment, but sufficient containers and suitable transport facilities. The main investment must be on personal and on educational training for citizens and also for waste collectors.
- A stepwise implementation of waste management options is recommended as demonstrated with the scenarios 1 and 2 using existing facilities. Although, even scenario 2 does not aim at a maximum mitigation potential both scenarios reveal considerable GHG mitigation effects. Both are considered feasible and comparably easy to implement on a cost-effective basis. However, scenario 2, with the proposed modern anaerobic digestion plants would need higher investments which are not likely to be covered by sales of biogas and compost only. Such a concept needs other financing sources like waste service/gate fees.
- Additionally, at least for medium sized and large/mega cities waste incineration is seen as a necessary option for rejects and impurities from pretreatment and for RDF fractions which cannot be used for co-incineration in cement kilns. Here again, suitable fractions need to be

identified. Cluster WtE and/or co-incineration in WtE plants for agricultural residues are options for smaller waste streams because WtE plants need a minimum throughput of suitable material to be economically viable.

- In general, municipalities should examine possibilities for cooperation with other cities or other sectors to realize e.g. a cluster WtE concept, co-incineration in cement kilns, co-incineration in WtE plants for agricultural residues or co-processing of organic waste in biogas plants for energy crops and/or agricultural residues. However, in any case for waste incineration a proper flue gas cleaning is mandatory to respect human health concerns. Incineration must comply with the emission standards of the SWM Rules 2016, and also co-processing of MSW in other sectors always needs to examine first if this is compliant with environmental needs.
- The leaders of municipal cooperation, cities and states need to be convinced to put more emphasis on development plans for the waste sector and to dedicate adequate resources to the improvement of MSW management. There is still need for more and other types of funding. Financial means may be provided to some extend by implementing the requirement of the MSW Rules 2016 for user fees for solid waste management. Additionally, climate mitigation related funding, producer responsibility, support through energy pricing or environmental funds or others should be considered for developing appropriate and climate friendly integrated waste management systems and infrastructure.

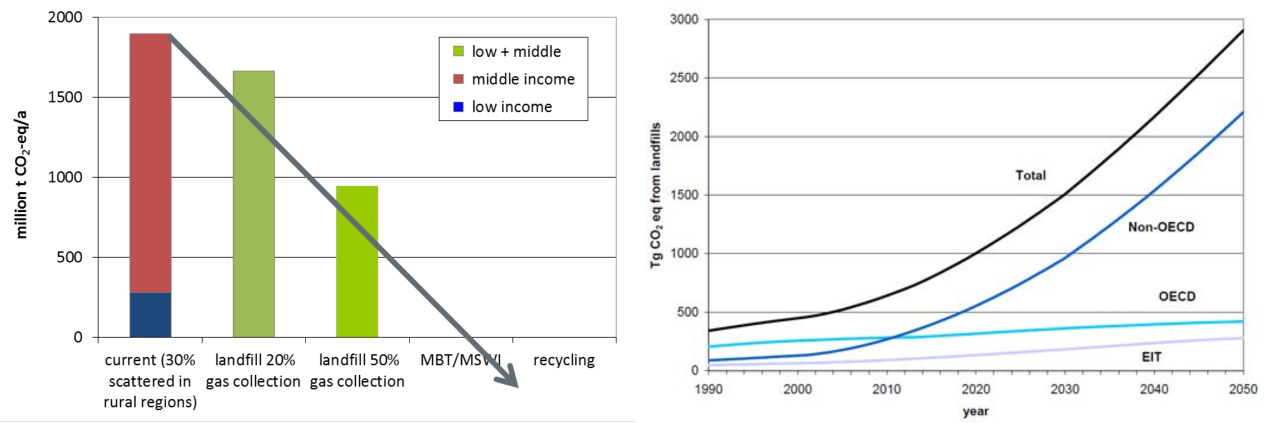
The extrapolation of the GHG results for city clusters displays that the potential contribution of small cities to national GHG mitigation is relevant and should not neglected. Although, large-scale projects in large or medium sized cities definitively have a significant GHG mitigation potential, in smaller cities the opportunities for sound source segregation might be higher and the technologies applied in cities of that scale, like composting, might be faster to implement and are easier to operate.

Support of small cities could be bundled on regional or national level programs allowing financing institutions and climate funds to get involved, because the financing scale is large enough. Such programs should cover training on methods for waste sampling and waste analyzing in the smaller cities as well as, for example, the development of a standard construction pattern for biological treatment. An ideal effect would be if companies would specialize on such ‘small scale solutions’ like for example composting as this would give a merit of order effect for other cities.

1 Introduction

The relevance of the waste sector in emerging economies and developing (E+D) countries for greenhouse gas (GHG) mitigation was demonstrated in several studies. According to findings in Dehoust et al. (2010), the development of integrated waste management systems could reduce 12-18% of annual GHG emissions in E+D-countries. Usually landfilling is dominating solid waste management (SWM) practices in E+D-countries. Giegrich and Vogt (2009) demonstrated the global dimension of potential GHG emission savings from the waste sector in E+D-countries by diversion from landfill. About 2 million tons CO_2-equivalents or more could be mitigated (Figure 1, left). The future development of GHG emissions from the waste sector in non-OECD countries was estimated by Monni et al. (2006) assuming an increase of waste generation with population growth and no further actions taken (Figure 1, right). The continued landfill practice would lead to at least 3 times higher GHG emissions by 2050.

Figure 1: left: Potential GHG emission savings in E+D-countries (Giegrich and Vogt 2009); right: future GHG emissions of the waste sector in E+D-countries (Monni et al. 2006)



The significant GHG mitigation potential of the waste management sector has been demonstrated for several countries and regions in previous studies commissioned by the German Environment Agency (Dehoust et al. 2010, UBA 2011, Vogt et al. 2015). Not only E+D-countries but also OECD countries can still contribute significantly to climate protection by changing their waste management system. In total, they still show GHG debits in the net results of the LCA, with methane emissions from landfill as main contributor (Vogt et al. 2015).

In Germany, waste management changed significantly since the beginning of the 90ies. Political and legal framework enabled a paradigm change from disposal to a recycling and/or circular economy. Especially, the landfill ban, which is in effect since 2005, has extensively ceased methane emissions thus considerably contributing to climate protection. Ever since municipal solid waste (MSW) is more and more source-separated, recycled or recovered. (Dehoust et al. 2010, UBA 2011)

For E+D-countries the graphics in Figure 1 illustrate the high relevance of landfilling with respect to GHG emissions. Consequently, actions and improvements to divert waste from landfill and to implement landfill gas utilization projects at existing landfills where appropriate would be necessary. As a first simple step stabilization of organic waste could be done from a mixed waste fraction using mechanical-biological treatments. In general, the aim should be to comply with the waste hierarchy in consideration of the material properties.

Thus, it is important for E+D-countries to know in detail the emission saving potentials of the waste sector and to consider them in their conceptual planning of waste treatment, e.g. in the frame of Nationally Appropriate Mitigation Actions (NAMAs) or Nationally Determined Contributions (NDCs). The present project aims at supporting countries in this. The project is embedded in the German-Indian bilateral environment cooperation and aims to support the Indo-German Joint Working Group (JWG) on Circular Economy and Waste. It shows specific GHG emission saving potentials of an integrated waste sector approach in exemplary research regions in India.

2 Objectives and Approach

The objective of the study 'Resource and Climate Protection through Integrated Waste Management Projects in India' is to support decision-makers in identifying the potential to reduce GHG emissions in the Solid Waste Management (SWM) sector in order to plan their waste management or e.g. NAMAs and NDCs accordingly. Ultimately, the project aims to indicate if/how the LCA approach in waste management (decision-making aid) can be connected to reporting requirements in line with UNFCCC, which are assumed to be required for an MRV (monitoring, reporting, verification) of Waste-NAMAs, NDCs and others.

Importance was attributed to a profound exchange with relevant stakeholders and contacts to relevant stakeholders taking into account their interest in participating in waste sector improvements, which are regarded as a precondition for sustainable support. The study refers to three specific selected cities, which are selected on the one hand based on information on India and, to some extent, at federal state or local level, and on the other hand based on prioritized selection criteria (chapter 3), of these stakeholder interest is one of. The selection process aims to respect the broad differences in sizes of Indian cities, which result in different framework conditions for waste management. In a rough approximation the selected 3 cities can be used as proxy for city size clusters, and extrapolating the results can give a rough idea of the national dimension of GHG mitigation scenarios (chapter 8).

The cities selected are Bangalore, Bhopal and Haridwar, with Bangalore to start with. To enable systematic interviews, and also receive information on data gaps and reliability of data, a comprehensive data template was established. This data template is based on the 'Data Collection Tool for Urban Solid Waste Management' developed by the World Bank[1] (2013) and is modified regarding the waste treatment sheets in order to focus on GHG emissions and to establish a systematic input data sheet for the GHG calculation. The data sheets also take into account that large/mega cities are organized in different governing areas and have various waste treatment sites (Annex, chapter 13.4). In addition, waste definitions were clarified especially for "Municipal Solid Waste" (MSW) and for relevant waste fractions. An extract of the terms/glossary and the definition of MSW used in the study is shown in the Annex (chapter 13.3).

The initial data collection phase included interviews with government officials, operators and experts. High population growth and migration into cities as well as the rapid change in life style confronts municipalities with an increase of waste generation and change in composition (see chapter 4).It is challenging for most municipalities in India to keep up with these dynamic changes in their urban perimeter. So, data collection and management is often of secondary concern for the public sector authorities. The interviews revealed that most important and critical data is not available at a central level, but dispersed at many and various levels, sometimes only in handwritten form. The necessity for primary data collection from such a multitude of disperse local sources had not been predictable and exceeded the research scope and design considerably. The project is therefore based on available secondary level data research, and the efforts to derive first-hand information through site visits and expert interviews were enhanced.

In addition, the workshops in and with the cities – initially meant to discuss optimization scenarios –

[1] Tool developed by the World Bank with a technical assistance grant provided by The Global Partnership on Output-Based Aid (GPOBA). The tool has benefited from the technical contributions of the solid waste initiative of the Climate and Clean Air Coalition (CCAC) and the Global Methane Initiative.

were readdressed to verify collected data and potentially close data gaps by sharing the findings with different stakeholders in profound discussions. Results from the workshops with stakeholders in Bangalore and Haridwar are summarized in workshop reports[2]. The facts and findings for the 3 cities that could be established and confirmed, are briefly described in chapter 5, while detailed reports for the 3 cities are published as separate Annex to this report.

Based on these information the GHG scenarios for the SWM were established with a status quo and 2 optimization scenarios for each of the 3 cities (chapter 6). The GHG scenarios and results were presented and discussed on the final workshop in New Delhi on January 31st, 2018, and at the environmental fair IFAT in Munich on May 15th, 2018.

In the light of the insufficient availability and quality of data and information on the one hand and the importance of reliable data on the other hand additional GHG calculations were performed to visualize the influence of waste data and/or varying parameters on GHG accounting results (see chapter 9).

All GHG calculations by this project use the life cycle assessment (LCA) method in waste management based on ISO 14040/14044. The advantage of this approach is the possibility to assess the holistic effects of waste management activities – both direct emissions as well as avoided emissions through substitution of primary products and energy. The results represent mitigation potentials applicable for decision-making in policy, public authorities and industry. The method and special considerations applying to waste management are described in the annex (chapter 13.1).

In contrast to the LCA approach in waste management, National Inventory Reports (NIR) under the Kyoto Protocol aim to monitor GHG emissions from all sectors in a national economy. Therefore, yearly emissions are reported (instead of emissions related to a waste amount), and crediting GHG emissions potentially saved in other sectors is not an option in order to prevent double accounting. Monitoring, reporting and verification (MRV) of GHG emissions and reductions are also required for NAMAs and likewise for NDCs. However, for the time being there is no harmonized or agreed method on how MRV should be implemented in this context. The status of NAMAs is documented in (Michaelowa & Friedmann 2017). A brief overview as well as practical aspects and challenges of MRV are described in chapter 10.

Another project task was to adapt GHG calculations to more specific technical and organizational aspects of waste management especially relevant in E+D-countries, for example different mechanical-biological treatment practices. In this context the GHG calculation methods was not only extended, but a GHG calculation tool for scientific users developed. To enable future assessments for further regions in E+D-countries, this ifeu tool (GHG model for solid waste management) was shared with the German Environment Agency under the condition that the tool itself is exclusively for internal use and not to be shared with any third party.

3 Selection of cluster cities

The selection of up to 3 cities was based on a set of relevant criteria (Figure 2, left). The criteria availability and quality of waste data, contacts to actors and stakeholders, and the interest of relevant stakeholders in participating to improve the waste sector were given a higher importance. Waste data are not only important to correctly calculate the status quo but also to understand the waste's properties,

[2] The workshop reports will be provided on www.umweltbundesamt.de under date and title of the workshops: "Resources and Climate Protection through Integrated Waste Management Projects in India"; Bangalore, 25th October 2016 and Haridwar 23rd March 2017.

and thus its treatment options. Furthermore, knowledge about local conditions like formal and informal activities, infrastructure, working conditions, man power, administrative framework and political support, market conditions for secondary products, climate, etc. are important to plan integrated waste management systems.

Based on researched information on these criteria and an information exchange with GIZ Delhi a shortlist for cities was established starting from the 59 cities analyzed by the Central Pollution Control Board for the time periods 1999/2000, 2004/2005 and 2010/2011 (CPCB 2011). The location of the 26 shortlisted cities is presented in Figure 2 on the right. These 26 cities were clustered depending on their population size:

- > 3 million:
  Ahmedabad, Bangalore, Chennai, Hyderabad, Pune.
- >1 to 3 million:
  Bhopal, Coimbatore, Gwalior, Indore, Jabalpur, Lucknow, Nashik, Rajkot, Vadodara, Varanasi, Visakhapatnam.
- 0.1 to 1 million:
  Bhubaneswar, Dehradun, Haridwar, Hubli, Kochi, Kota, Rishikesh, Shimla, Tirupati, Udaipur.

Bangalore was the first city selected from the cluster of large/mega cities due to very good contacts, proactive stakeholders, and an available sorting analysis study undertaken by ISAH Hannover, Germany (final publication: Weichgrebe et al. (2016)).
Haridwar was selected from the cluster of small cities to follow a request of the Indo-German JWG on Waste to consider a city situated at the Ganga river.
Bhopal was selected from the cluster of medium sized cities due to its location in one of the major states of India characterized by a different income level compared to Karnataka and Uttarakhand.
The major characteristics of the 3 selected cities are summarized in Table 4.

Figure 2: Selection Criteria for the 3 cities (left) and location of the 26 shortlisted cities (right)

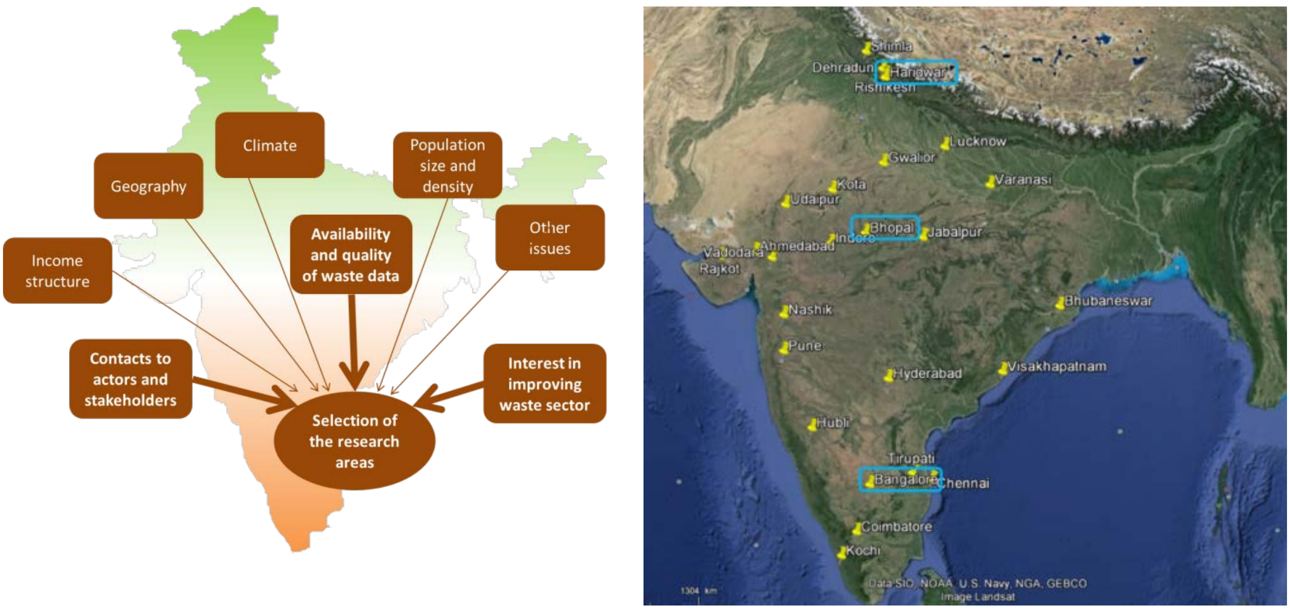


Table 4: Characteristics of selected cities

City		Bangalore	Bhopal	Haridwar
State		Karnataka	Madhya Pradesh	Uttarakhand
Administrational level / area		state capitol	state capitol	sacred city at Ganga
Per capita income of state	1000 INR	75-100	30-50	75-100
Urbanization rate	%	38.7	27.6	30.2
Population as per census 2011[1)]		8,495,492	1,798,218	228,832[2)]
Area[1)]	sq. km	740.64	285.88	12.17
climate zone Köppen Geiger classification		Aw: tropical, winter dry	Aw: tropical, winter dry	Cwa: humid subtropical, winter dry, warmest month >22°C

1) Information refer to city level
2) the additional floating population is estimated to 165,000 people per day on average (CPCB 2016)

Sources: (ORGI 2015 & 2018); (MapsofIndia 2015); (vetmed 2015)

4 SWM in India – an overview

Solid waste management may be regarded as a huge challenge for India. The continuous increase of waste generation and change in composition on the one hand, and restricted capacities on the other hand result in lack of data knowledge and provision of appropriate treatment options. The SWM status in India as well as the previous legal situation is briefly described in chapter 4.1. Deficiencies from the latter have been addressed by revised versions, the SWM Rules 2016 (MoEF 2016), and the MSWM Manual 2016 (MoUD 2016), which are described in chapter 4.2. To address financial constraints the Government of India has invested significantly in SWM projects under the 12th and 13th Finance Commission (Michaelowa et al. 2015). Some of these programs and some regional SWM related programs and initiatives as well as the participation of the 3 selected cities are described in chapter 4.3.

4.1 Status and previous legal situation

For 2011, the daily waste generation in India is estimated to 133,760 tons, of which approximately 70% are collected and about 13% are treated, while non-collected waste is basically scattered and non-treated waste disposed in open dumps (Joshi & Ahmed 2016, citing CPCB report 2013). According to Kumar et al. (2017) the informal sector has a key role in extracting value from waste, but approximately more than 90% of residual waste in India is dumped in an uncontrolled manner. Consequently there is a need to develop facilities to treat and dispose of increasing amounts of MSW. The factsheet on Municipal Solid Waste Management prepared by the Indo-German Environment Partnership (GIZ-IGEP 2015) states that segregation at source, collection, transportation, treatment and scientific disposal of waste is largely insufficient leading to degradation of environment and poor quality of life.

The MSW generation in Indian cities ranges from 0.17 kg to 0.62 kg/capita/day depending on population size and its socio-economic profile (GIZ-IGEP 2015). The same data are reported in greater detail by Kumar et al. (2017) with waste generation rates for four different city sizes, ranging from 0.17 kg to 0.54 kg/capita/day in small towns (< 0.1 million inhabitants) to 0.22 kg to 0.62 kg/capita/day in large cities (> 2 million inhabitants). The data have been derived from an earlier study (from Kumar et al.

2009) on 59 cities.

There are several studies on waste data for cities in India available. However, these data are partly outdated or not representative, e.g. with regard to waste composition, where samples are often taken haphazardly instead of systematically from various spots, at different times of the year and in sufficient number. Joshi & Ahmed (2016) state that in India, due to lack of availability of primary data on per capita waste generation, inadequate data on waste characteristics, and influence of informal sector activities, various reports give different values and projections on landfill space required, and that it is therefore difficult to assess the land requirement or to select appropriate treatment/disposal techniques.

MSW management in India has not changed much in the past decade. Although, a regulatory framework as well as a MSW manual have been prepared and implemented by nodal ministries in 2000 (MSW Rules 2000, MoEF 2000; MSW Manual 2000, MoUD), the responsible municipal authorities (Urban Local Bodies - ULBs) could not fully comply with the guidelines. The framework, among others, prohibited littering of MSW, restricted landfilling to non-biodegradable or inert waste, and set standards for composting and incineration. The MSW Rules 2000 offered a range of options that individual municipalities could choose from. However, often the municipalities lacked information about advantages and disadvantages of these options, and on how to implement an integrated solid waste management system. Furthermore, municipalities had limited information on costs or environmental and social impacts resulting from different options. Another reason for non-compliance with the MSW Rules 2000 could be difficulties like budget constraint and lack of capacity in executing solid waste management projects. These deficiencies have been addressed by revised versions.

4.2 Current rules and guidelines

The "MSWM Manual 2016" (MoUD 2016) provides a seven-step approach for developing a municipal solid waste management plan in ULBs, including a gap analysis of the current status (step 2) with detailed information on data collection methodologies to derive representative data on waste quantities and composition of waste.

The "SWM Rules 2016" (MoEF 2016) extended its scope beyond the municipal perimeter to cover outgrowths in urban agglomerations, census towns, notified industrial townships or areas under the control of Indian Railways and airports. Further salient features of the SWM Rules are for example the duty for segregation which is put on waste generators and the responsibilities of local authorities:

- Waste generators shall (rule 4):
  - separate and store bio-degradable, non-bio-degradable and domestic hazardous waste in suitable bins and hand it over to authorized waste pickers or collectors;
  - store separately construction and demolition waste as per the C&D Waste Management Rules, 2016;
  - store horticulture and garden waste separately in own premises and dispose of as per directions of the local body,
  - pay user fee for solid waste management as specified by the local bodies; littering is prohibited.
- Organizers of events with more than 100 persons shall ensure segregation of waste and hand it over as specified by the local body, and street vendors shall keep suitable containers and deposit the waste as notified by the local body,
- Resident welfare and market associations, gated communities and institutions with more than 5,000 m^2 area as well as hotels and restaurants shall, within 1 year in partnership with the local body:

- ensure segregation of waste,
- handover recyclable materials to authorized waste pickers or collectors,
- process, treat and dispose off bio-degradable waste through composting or bio-methanation within their premises as far as possible,
- give residual waste to waste collectors or agencies as directed by the local body.

- Local authorities on the other hand are for example responsible to
  - arrange for door-to-door collection of segregated solid waste from households including slums, informal settlements, commercial, institutional and other non-residential premises; the waste from bulk generators may be collected from the entry gate or any other designated location (rule 15 (b)),
  - support integration of the informal sector e.g. by establishing a system to recognize organizations of waste pickers or collectors to facilitate their participation in SWM, and to facilitate formation of Self Help Groups, provide identity cards and encourage integration (rule 15 (b) (c)),
  - collect market waste and to promote setting up of decentralized compost or bio-methanation plant at suitable locations in the markets or in their vicinity (rule 15 (m)).

Also a comprehensive monitoring system is established. Operators of facilities have to submit annual reports to the local body (Form III), which themselves then have to submit annual reports to regulatory authorities (Form IV) which are further reported and centralized first on state level (Urban Development Department and SPCB/PCC) and then on national level (CPCB, MoUD, MoEF). MoEF has the responsibility for over all monitoring the implementation of the rules in the country, and shall therefore constitute a Central Monitoring Committee for yearly review (rule 5).

Financial and capacity building support for SWM is requested from public sector authorities, for example:

- MoUD shall undertake training and capacity building of local bodies and other stakeholders, and provide technical guidelines and project finance to the states, Union territories and local bodies to facilitate meeting timelines and standards (rule 6 (e) (f));
- the Department of Fertilizers, Ministry of Chemicals and Fertilizers shall provide market development assistance on city compost and ensure promotion of co-marketing of compost (rule 7);
- the Ministry of Agriculture shall provide flexibility in Fertilizer Control Order for manufacturing and sale of compost, propagate utilization of compost on farm land, set up laboratories to test quality of compost, and issue suitable guidelines for maintaining and application (rule 8);
- local authorities shall phase out the use of chemical fertilizer in 2 years and use compost in all parks, gardens maintained by the local body (rule 15 (u)), and shall make adequate provision of funds for capital investments as well as operation and maintenance of SWM services in the annual budget (rule 15 (x));
- the Ministry of Power shall decide tariff or charges for the power generated from solid waste, and compulsory purchase such power generated (rule 9);
- MNRE shall facilitate infrastructure creation for Waste-to-energy (WtE)-plants, and provide appropriate subsidy or incentives for such plants (rule 10);
- industrial units using fuel and located within 100 km from refuse derived fuel (RDF) and WtE plants shall make arrangements within 6 months to replace at least 5% of their fuel requirement by RDF.

Some further salient rules on SWM are:

- local authorities shall apply for grant authorization for setting up waste processing, treatment or disposal facilities > 5 TPD including sanitary landfills from SPCB/PCC (Form I) (rule 15 (y));

- they shall create public awareness and educate waste generators e.g. on practice home composting, vermi-composting, biogas generation or community level composting (rule 15 (zg));
- landfilling of non-treated usable waste is not allowed (rule 15 (zi)), but till the time waste processing facilities are set up waste shall be sent to sanitary landfill (schedule I, (C-ii));
- non recyclable waste with a calorific value ≥ 1,500 kcal/kg (about 6.3 MJ/kg) shall only be utilized for generating energy, whereof high calorific wastes shall be used for co-incineration (rule 21);
- standards for compost quality are extended by e.g. values on nutrient content (schedule II, A), and standards on incineration are widely broadened and now correspond widely to emission standards in Germany/Europe.

4.3 SWM related programs and initiatives relevant for the selected cities

4.3.1 Swachh Bharat Mission (Clean India Mission)

Swachh Bharat Mission (SBM) is a national campaign implemented by the Ministry of Urban Development (MoUD) and by the Ministry of Drinking Water and Sanitation (MoDWS) for urban and rural areas in India to ensure hygiene, waste management and sanitation across the country. The mission lays down specific guidelines to be followed by governing bodies on national, state and city level. Its main focus is the target of 100% open defecation free (ODF) India. In the context of solid waste management the targets are 100% door-to-door (D2D) collection, organic waste treatment (waste to compost) and waste to energy. According to the statistics by Swatch Bharat website, D2D collection of MSW has been implemented in 55,913 wards of the total 82,607 in India up to November 2017[3].

In Bangalore D2D collection and waste to compost are being promoted as part of the project. Bhopal is one of the cities in the state Madhya Pradesh receiving funds for SWM initiatives, and also Haridwar received funds as part of the Swachh Bharat Mission (MoUD 2016, Uttaranchal High Court 2017), which intends to improve sanitation and solid waste management.

4.3.2 JNNURM and AMRUT

The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was a national scheme launched by the Government of India and the Ministry of Urban Development to improve urban infrastructure and services identifying 65 cities for the program. It envisaged a total investment of over 20 billion US $. The seven-year mission was to end in 2011-12, but repeated extensions were given due to delayed implementation for reasons like land acquisition. The scheme was closed in March 2015 (TNN 2015). The program supported cities to improve their infrastructure services in a financially sustainable manner, to (re-)develop their area, to develop urban reforms and appropriate framework, and to make their services available to the urban poor. Half of the cities covered by JNNURM are cities with more than one million inhabitants, the rest are state capitals or cities of special interest like Haridwar. (IPE 2009, Urban Development Directorate 2015)

Bangalore received the highest number of approved projects, although most of the funds are for infrastructure development and the metro rail development. In Bhopal, about two thirds of projects approved by JNNURM focused on water supply and most of the other approved projects focused on urban transportation (Smart Cities Projects 2015). Consequently, this program had little impact on solid waste management in Bhopal. Haridwar's JNNURM project was approved in 2009 and includes procurement of waste management equipment, launching of D2D collection and construction of an integrated SWM

[3] http://www.swachhbharaturban.in/sbm/home/#/SBM

facility (Urban Development Directorate 2015). Nevertheless, when the scheme was closed in 2015, not even half the funding for Haridwar's project had been disbursed, and follow-up financing was needed, which was partly provided by Uttarakhand's state government (Nagrath 2016).

AMRUT, Atal Mission for Rejuvenation and Urban Transformation, is the follow up program of JNN-NURM, also launched by the Government of India and the Ministry of Urban Development. The program has funds allocated of 500 billion rupees (nearly 8 billion US $) for five years from 2015 to 2020. It covers 500 cities, including Bhopal and Haridwar. However, AMRUT focuses on infrastructure linked to better services to people especially in water supply, sewerage facilities, parks and urban transport. Solid waste management is not a thrust area of AMRUT. (MoUD 2015)

4.3.3 Namami Gange (Clean Ganga)

Namami Gange is a program of the National Mission for Clean Ganga and intends to stop pollution of the river Ganga and to revive the river (NMCG 2017). It focuses on sewage treatment, river-front development, river surface cleaning, biodiversity, afforestation and public awareness.

For Haridwar situated at the Ganga river several sewage treatment projects have been approved under Namami Gange. Though the Clean Ganga Mission does not target solid waste management itself, it funds systems to address floating solid waste in the river and to reduce entry of solid waste into the river as a result of poor sanitation practices in rural areas.

4.3.4 Smart Cities Programm

Smart Cities Mission is an initiative to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of 'Smart' Solutions. The focus is on sustainable and inclusive development and the idea is to look at compact areas, create a replicable model which will act like a light house to other aspiring cities. The Indian government has allocated 1.2 billion US $ for Smart Cities in Union Budget 2014-15. It is anticipated that financing will mostly take place as full private investments or through Private Public Partnerships, and that the state contribution will be largely by way of viability gap support (Michaelowa et al. 2015).

Bangalore and Bhopal were on the list of the 98 cities nominated by states for the smart city challenge, and Bhopal was one of the top 20 selected in the first round in January 2016. Bangalore was selected in round 3 in June 2017. With the final round 4 in January 2018 there is now a total of 99 cities in the Smart Cities Mission[4].

4.3.5 Examples for regional programs, Bangalore

Many programs also exist on regional level. Two of these which are in place in Bangalore are the "2Bin 1Bag Initiative" and "I got garbage" which are described in the following.

1. **2Bin 1Bag Initiative, Bangalore**

2Bin 1Bag – divide and conquer waste is an initiative by citizen groups that work proactively with the government at finding solutions for waste management. The movement is a combined effort of multiple citizens groups in Bangalore including the Kasa Muktha Bellandur, HSR Citizen Forum, We Care for Malleswaram, Solid Waste Management Round Table (SWMRT) and many others, where waste segregation at household level is practiced and promoted at community level. The program has also been identified and supported and further taken up by Bruhat Bangalore Mahanagara Palike (BBMP, the Bangalore Municipal Corporation). BBMP has started collecting waste in segregated manner from

[4] http://smartcities.gov.in/content/Whatsnews.php

household level in support to the program. Wet waste, dry waste and sanitary waste is collected in separate bins/bags and managed separately. The initiative is supported by court orders, public awareness campaigns and imposing penalties for non-cooperation. The high-court of Karnataka has passed an interim order on December 17, 2015 to citizens in Bangalore to mandatorily practice 2bin 1bag system[5].

2. **I got garbage**

I Got Garbage is a Corporate Social Responsibility (CSR) initiative of Mindtree in the area of rag-picker livelihood and solid waste management. An important goal is to involve citizens and communities in solving the problem of managing solid waste, such that collectively jobs are created for rag-pickers, and also cities are made cleaner. The prime action city for the initiative is Bangalore.

I Got Garbage is basically a cloud based IT platform, and offers capabilities such as an Enterprise Resource Planning (ERP) for rag-pickers, Citizen Engagement Platform, Waste Management Services Marketplace, and a Rag-picker Benefits Tracker. Additionally, they work with social businesses towards process improvement as well as help build partner ecosystems. Since 2013 the initiative has supported the recycling of more than 9000 tons of waste in addition to creating job opportunities and green environments. The rag-pickers pick both wet waste and dry waste from their clients; the dry waste is transported to DWCCs in Bangalore whereas wet waste is converted into biogas and compost[6].

5 Facts and findings of SWM systems in the selected cities

The following chapters give an overview of facts and findings in the 3 selected cities. More detailed information is provided in reports for the 3 cities which are published as separate Annex to this report.

5.1 Bangalore

The city of Bangalore is the administrative and political capital of the state Karnataka. It is also an important commercial center with some of the major industrial establishments[7]. The city has earned the titles of "IT Hub of Asia" and "Silicon Valley of India." However, while the IT based formal sector accounts for 15% of its economy, the informal sector contributes 60-70% (BDA 2005).

5.1.1 Geography and climate

Bangalore is located on the southern part of the Deccan plateau at an altitude of 949 meters (3113 ft.) above sea level. Bangalore metropolitan covers an area of about 800 km².

According to the Köppen Geiger climate map (Peel et al. 2007) the area is classified as "Aw", tropical wet and dry or savanna climate. The climate is seasonal with dry season from December to May, followed by the southwest monsoon season from June to September, and October, November constitute the northeast monsoon season. The main features of the climate of Bangalore are the agreeable range of temperatures, from the highest maximum of 33°C in April to the lowest minimum of 14°C in January. The mean monthly relative humidity is lowest in March (44%) and highest between June and October (80-85%). The mean annual rainfall is 860 mm whereof June to September being rainy season receives 54% in the S-W monsoon period and October and November 28% during the N-E monsoons.

[5] http://www.2bin1bag.in/
[6] http://www.igotgarbage.com/
[7] http://ces.iisc.ernet.in/energy/wetlands/sarea.html

5.1.2 Population and city structure

Bangalore has the reputation of being one of the fastest growing cities in Asia (Ramachandra & Bachamanda 2007). As per census of India 2011 the city Bangalore had a population of about 8.5 million (ORGI 2015) experiencing a steady increase in population (3.25% current annual growth rate). It is likely to have 10 million inhabitants by 2021. Bangalore city is structured into 198 wards in 8 sub-administrative zones (Figure 3).

The municipal authority in Bangalore is called Bruhat Bangalore Mahanagara Palike (BBMP). BBMP represents the third level of government (the Central and State Governments being the first two levels), and is run by a city council that comprises corporators (or elected representatives) with one corporator representing each ward of the city. Elections to the council are held once every 5 years. A mayor and deputy mayor of the council are also elected for a period of 1 year, though not by popular vote.

Bangalore is the 4th most developed city in India and ranked number 84 among developed cities worldwide with a total GDP of about 83 billion US $. The city is the third largest hub for high net worth individuals after Mumbai and Delhi[8]. The Government policies contributed towards development of industries in Bangalore. Karnataka Government in late 80's created the Electronic City, 18 km from Bangalore (nowadays ingrown in the Urban Agglomeration), for the software and electronic industries. Several Technology parks were created in the last decade to host hundreds of companies.

Figure 3: Zones and wards in Bangalore

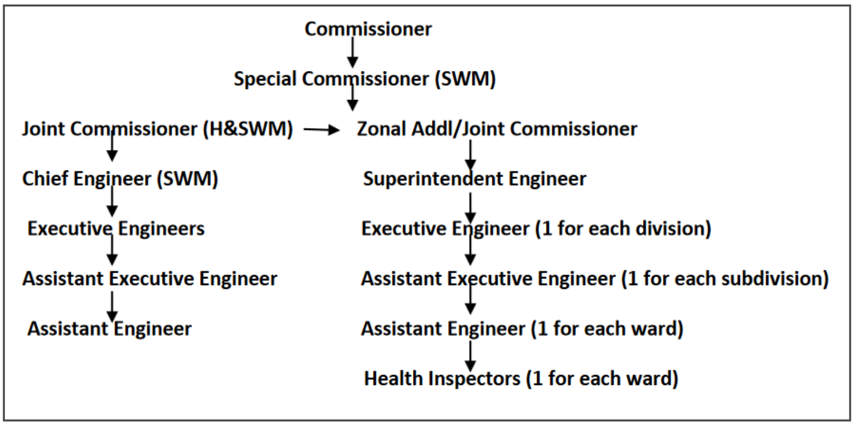
Cartography: ifeu; spatial data based on CC BY-SA 3.0, http://openbangalore.org

[8]http://top10wala.in/top-10-most-developed-city-in-india-by-gdp/

5.1.3 Municipal solid waste management

Solid Waste Management in Bangalore is handled by the SWM Department headed by the Special Commissioner for SWM. The organizational structure of the SWM Department is shown in Figure 4. BBMP is responsible for the collection, street sweeping, transportation, treatment and disposal of MSW. All so-called bulk generators like trade and commerce, markets, hotels, canteens, apartment and high-rise blocks – thus a considerable amount of the waste generators in the city – are required to manage their waste either in-situ or to contract BBMP authorized private service providers (KSPCB 2014). In addition, several NGOs and welfare groups are involved in waste management. Municipal SWM is financed through property tax and in some areas an additional charge is collected from households.

Figure 4: BBMP organizational chart of Solid Waste Management



Source: BBMP website[9]

5.1.3.1 Waste generation and composition

Data available on MSW generation vary between 3,000 and 4,000 TPD (BBMP 2016b, TERI 2015, KSPCB 2014). These amounts do not include waste generated by bulk generators which is assumed to be an additional 1,700 TPD (UMC 2015). Also recyclable waste processed by the informal sector is not included in these figures. The respective amounts are assumed to be relevant though data are not available.

Approximate data on waste composition, meant for guidance only, are available from BBMP and are presented in Table 5. In addition, Table 5 shows the waste composition taken from a study on the West Zone (Weichgrebe et al. 2016). Though this study results are derived from a comprehensive analysis it was not used for the GHG calculations because experts participating on the Workshop in Bangalore on 25th October, 2016 stated that the data from West Zone are not applicable to other zones in Bangalore. In the light of the given situation the composition from BBMP is used in the calculations as approximation.

[9] http://bbmp.gov.in/documents/10180/512162/Organization+Chart+of+Solid+Waste+Management.pdf/2697cd91-79d5-4785-8ed2-d7ce4d0e8d7b; last access 17-04-2017

Table 5: Waste composition in Bangalore

Waste fraction	General Bangalore [%] (Approximate, for guidance only)[1)]	West Zone [%][2)]
Organic and Vegetables	53	62.6
Paper & Cardboard	13	8.8
Plastic	12	9.9
Wood	6	0.4
Textiles	4	4.6
Composites		3.3
Glass	3	1.5
Electronic Item	2	0.1
Metal	1	0.3
Inert (debris & fines)	5	5.8
Biomedical & household hazardous waste	2	2.8

Source: (1) BBMP (2016a), (2) Weichgrebe et al. (2016)

5.1.3.2 Collection and treatment

BBMP is providing daily waste collection service to all households, slum areas, shops and establishment (BBMP 2016b). Bangalore is a bin less city, with bins/litter bins only in the commercial areas. MSW collection without bins is done by D2D collection and collection from so-called litter spots (areas along the roadside). About 80% of all collection and transportation activities are outsourced. Auto tipper, autos and pushcarts are used for the primary collection. About 20,000 Street cleaners, called Pourakarmikas, work for BBMP and contractors in D2D collection, street sweeping and transportation of MSW.

BBMP has emphasized segregation at source. Information Education and Communication activities are being intensified and penalties levied for non-compliance. In general, 3 categories of waste are destined for source segregation: dry waste, wet waste (defined as biodegradable waste) and sanitary waste. During the data collection phase this source segregation was hardly implemented. Dry waste contained non-recyclables or low quality material. The wet waste fraction was actually a mixture of non-segregated dry waste, textiles, biodegradable waste and sanitary waste.

Although, the collection coverage is 100%, not all MSW is really collected. On the Workshop in Bangalore, the non-collected share of the generated MSW was estimated to 20% by the judgment of stakeholders and experts. It is assumed that the non-collected MSW is 90% dumped in an uncontrolled manner, 8% burned openly and 2% home composted. These assumptions are used for non-collected waste in the GHG calculation of the status quo.

The collected MSW is brought to a transfer station, where dry waste is partly further sorted, while the wet/mixed waste fraction is transferred to the treatment sites through compactors & tipper lorries (Figure 5). The share of dry waste varies between 17% and 41%, according to information collected on zonal level for 3 zones. For the GHG calculation an average share of 25% dry waste was assumed.

Figure 5: Door-to-Door collection (left) and tipper to compactor (right)

Photos by ifeu

For dry waste treatment BBMP and selected NGOs operate 185 Dry Waste Collection Centers (DWCC) in Bangalore. NGOs mainly operate large, well organized centers which additionally process dry waste from bulk generators (Figure 6).

Figure 6: Dry Waste Collection Centers operated by NGOs, South Zone, Bangalore

Photos by ifeu

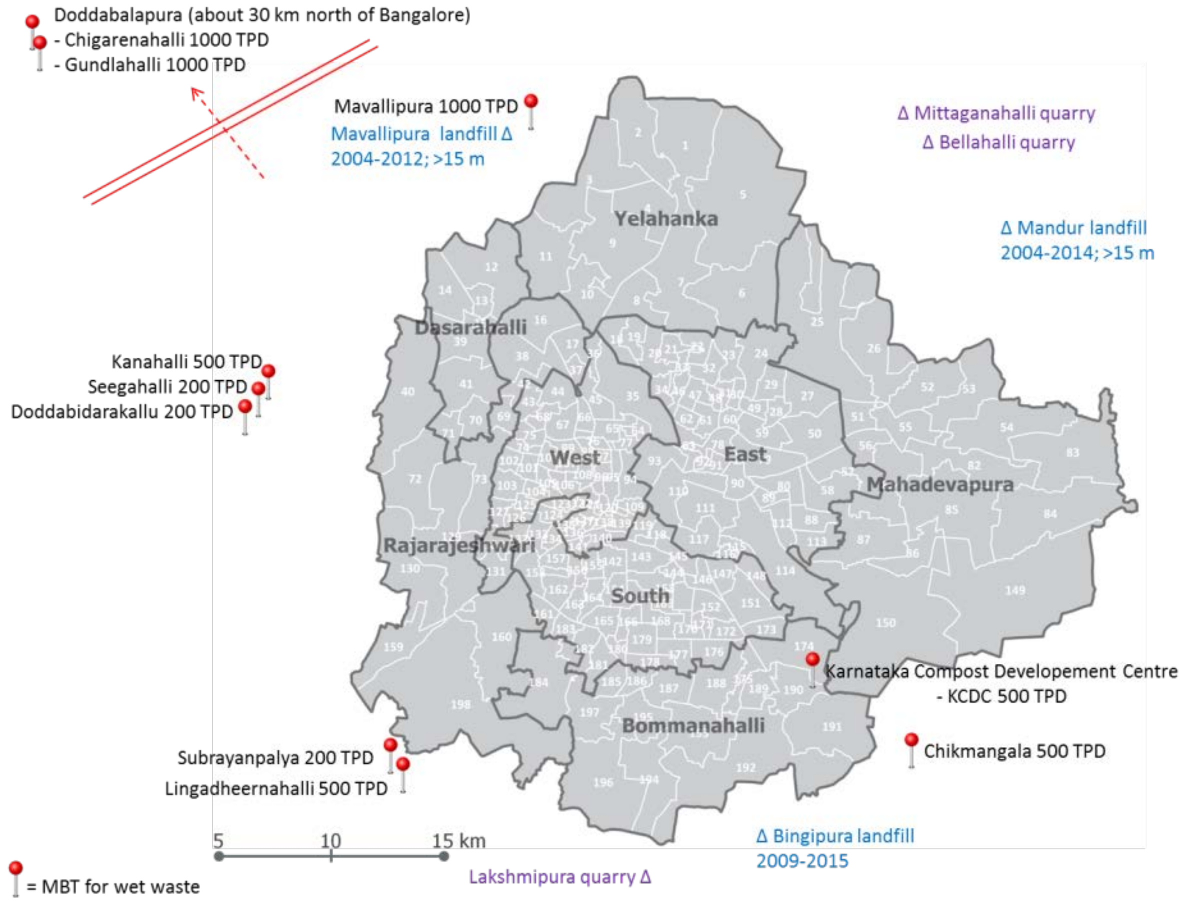
It is assumed that 30% of the dry waste delivered to the DWCCs is of low quality or non-recyclables, and are therefore not accepted at the DWCCs and basically end up on dump sites. The dry waste accepted at the collection centers is weighted, payed for and then manually sorted accurately. The recovered material, presumably 80% of the accepted input[10], is sold to industries or recyclers while rejects from the

[10] Average derived from 3 DWCCs, acknowledged as plausible by experts on the Bangalore workshop.

sorting process are dumped. These figures are also used for the GHG calculation of the DWCC.

The wet/mixed waste is taken to one of 10 mechanical-biological treatment plants (MBTs) which are mostly located outside the city with the farthermost about 30 km north of Bangalore. Figure 7 shows the MBTs in and near Bangalore as well as the 3 closed dump yards (Mavallipura, Mandur, Bingpura) and some uncontrolled dumps or quarries (rough location either from open space data or as informed by experts from the Bangalore workshop).

Figure 7: MBTs, closed dump yards and uncontrolled quarries/dumps in and near Bangalore (as of data collection phase 2016/2017)



Cartography: ifeu; spatial data based on CC BY-SA 3.0, http://openbangalore.org

The MBT plants have a capacity between 200 and 1,000 TPD and are operated by 7 different operators. The KCDC plant used to be a composting plant for source segregated biodegradable waste owned by the Karnataka State. In 2015 the plant was handed over to BBMP. Since then wet/mixed waste is processed and the capacity was extended from 300 to 500 TPD. 6 out of the 10 MBTs are newly build plants which were set up after high court order of Karnataka in 2012 to close Mavallipura landfill and not to dump waste the way it has been (TERI 2015). The 6 newly built plants are constructed in a similar way in a modular concept:

1. delivered waste is weighed on an electronic weigh bridge
2. from the waste tipping pit waste is mechanically pre-treated by a 200 mm trommel screen followed by 100 mm trommel screen
3. rejects are transferred to the RDF storage area
4. remaining waste (< 100 mm) is taken to the compost pad, and arranged in the form of trapezoidal heaps (windrows), 3 m high and about 4-5 m wide

5. windrows are turned by wheel drivers about once a week, water is added if necessary
6. after 4-5 weeks the semi-matured material is sieved through 40 mm and 16 mm trommel screens, rejects are transferred to the RDF storage area
7. throughput (< 16 mm) is stored in a section for 12 days for further stabilization
8. stabilized material is refined using a 4 mm trommel screen, rejects are re-introduced in the composting process, and the finer material, the final compost product, is packed for purchase

According to information from interviews and literature the MBT outputs vary from 50% RDF, 25% compost (Chikmangala) to 22% RDF, 22% recyclables, 11% compost, 44% rejects (Mavallipura) to 30% RDF, 12%-15% compost, and otherwise moisture and inert materials (TERI 2015). At the workshop in Bangalore an average MBT output of 20% RDF, 20% compost, 15% stabilized residues, 10% inert, 35% losses were determined in discussions with the stakeholders and are used in the GHG calculation.

However, in 2016 RDF derived from treatment was basically stored in the RDF storage or dumped on-site due to their low quality. Generally the plants are equipped with some shredder and bailing aggregates to further process the waste material to RDF. One of the plants visited tried to bail RDF and was in contact with a cement plant. The compost produced was offered for sale at a comparatively low price but there was no regular purchase of material. At the time of our visit in October 2016, 7 of the 10 MBT plants were not operating at all. Reasons were power cut-off due to unpaid bills and/or plants were blocked by citizens in protest. In one case a RDF storage fire caused disruption of operation[11].

Figure 8 shows pictures from a visit to the MBT Chikmangala in October 2016, which was kindly arranged by research staff from ISAH Hannover and by K S Velankani Bangalore. Pictures on the left from top to bottom depict the trapezoid windrows with the separated, supposedly biodegradable material from the first mechanical separation by trommel, the further separation step after 4-5 weeks and the final compost storage section. The first picture on the right shows the RDF fraction after initial separation. This material is not very different from the original input which is due to the fact that the mixed waste input consists of 2-3 m long textiles and flower festoon strings which regularly block the trommels and also clog the trommel screen where the biodegradable material is supposed to pass. However, the operator tried to further process the RDF by shredding and bailing but as shown in the next two pictures on the right with no success. The final RDF bails are of low quality consisting of relevant shares of inert and organic material and have a low calorific value of about 1,200 kcal/kg (5 MJ/kg). This material was rejected by cement kiln operators as not feasible for co-incineration (1) because of the low calorific value and (2) because of the inert/organic share which would end up in the cement klinker and affect the product quality negatively.

Based on these findings, no benefit was calculated in the GHG scenario for the MBT outputs in the status quo scenario.

[11] http://www.deccanchronicle.com/nation/in-other-news/151016/kannahalli-garbage-plant-still-on-fire-after-10-days.html

Figure 8: MBT Chikmangala, October 201

Photos by ifeu

Source segregated food waste from canteens or hotels is partly treated in small-scale biogas plants, so-called biomethanation plants. Altogether BBMP implemented 16 almost identical small-scale biomethanation plants with a capacity of 5 TPD. The plants are equipped from two technology suppliers with a crusher, digester, slurry tank, gas balloon and a 50 kW combined heat and power plant (CHP). The technology is rather simple without feeding pump or agitator. Food waste is shredded and mixed with water and directly introduced into the digester over the crusher, where it is pushed through by the daily feed, finally ending up in the slurry tank (see Figure 9).

Biogas generation is rather low, as the anaerobic process is not properly working and external power is needed. In October 2016 four of the 16 plants were operational. The process is not very climate- or environmentally friendly as the digestate from the slurry tank is drained to the water bodies.
The treatment was included in the status quo scenario but no benefit was calculated.

Figure 9: Small-scale biomethanation plant

Photos by ifeu and ecoparadigm

Apart from the described treatment practices for dry and wet waste some other NGO or welfare initiatives operate small-scale composting units for source segregated organic waste as shown in Figure 10. Source segregated organic waste is first treated in an Organic Waste Converter (OWC) (left picture). OWCs with a capacity of about 1 TPD are rather common in India. Typically after adding an activator the organic waste is processed for 1-3 days in the OWC. The NGO SAAHAS composts the material from the OWC for up to 40 days (right picture), while turning the compost every 3 days for aeration. Quality compost is produced corresponding to about 25% of the input. In October 2016 this compost could not be sold due to lack of market and market strategies.

Figure 10: Composting unit operated by the NGO SAAHAS

Photos by ifeu

The described composting process was not considered in the status quo scenario (1) because no data were available, and (2) the GHG calculations focus on MSW from households in the responsibility of the municipality.

5.2 Bhopal

The city of Bhopal is the administrative and political capital of the district Bhopal as well as the state Madhya Pradesh. Bhopal was one of the first selected cities under the smart city initiative in January 2016 (see footnote 4).

5.2.1 Geography and climate

Bhopal, also known as the 'City of Lakes', is located at an altitude of about 460 to 625 m above sea level spreading over 463 km². About 10% of Bhopal district's area constitutes the city of Bhopal and is administered by Bhopal Municipal Corporation (BMC) (Gaur et al. 2014, BMC 2006).

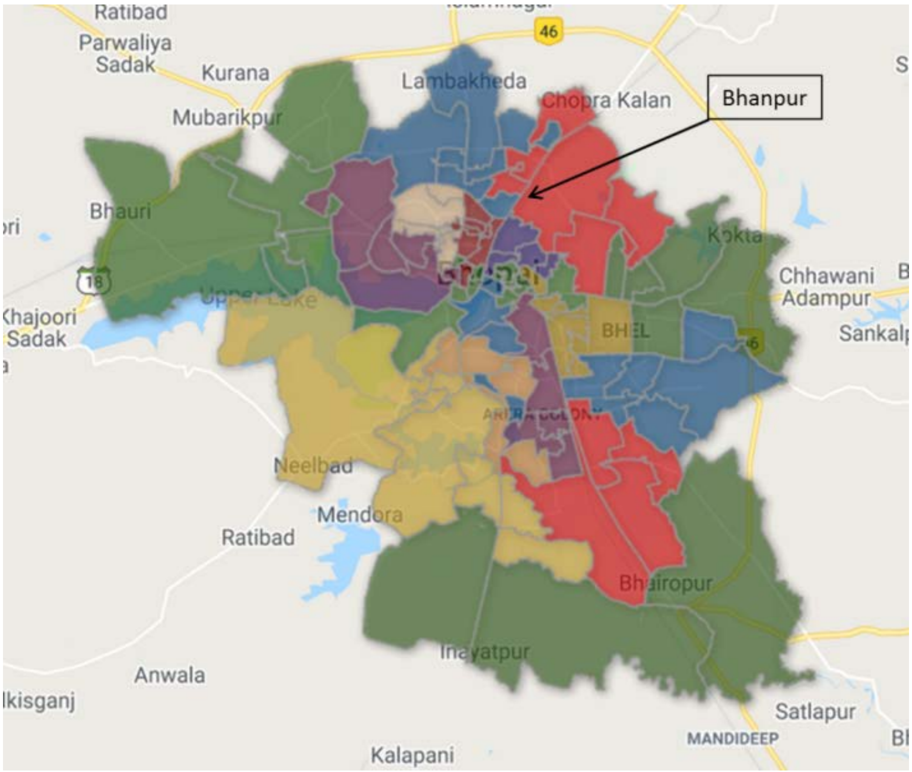
According to the Köppen Geiger climate map (Peel et al. 2007) Bhopal is located in a region classified as "Aw" climate zone. The main climate is tropical (A) with winter dry climate (w). The city's climate is considered moderate with hot summers and cold winters and temperatures between 10 and 43°C. The average annual rainfall is 1200 mm, falling predominantly during the monsoon season from July to September. The average number of rainy days is approximately 40 (BMC 2006).

5.2.2 Population and city structure

As per Census of India 2011, the population of Bhopal city was about 1.8 million. The Municipal Corporation governs about 94% of the district's total urban population. The average population density in the city is 6,290 persons per square kilometer. Also, a significant proportion (about 27%) of the population lives in the 388 slum areas across the city. (Smart Cities Projects 2015)

The city structure is presented with an informative map on the BMC website. Bhopal is divided into 85 wards, aggregated to 19 zones, and is headed by the Municipal Commissioner. Figure 11 shows a screenshot of the informative map. The indicated region "Bhanpur" roughly corresponds to the location of the Bhanpur dumpsite.

Figure 11: City structure Bhopal



Source: BMC Website (2017), http://www.bhopalmunicipal.com/city-information/informative-map.html

5.2.3 Municipal solid waste management

SWM is generally the responsibility of BMC. However, also several NGOs and Self-Help-Groups are involved in waste management. Bhopal's informal sector includes more than 8,000 recyclers, where BMC employs more than 4,700 personnel for SWM (CDIA 2015).

5.2.3.1 Waste generation and composition

Available information on MSW generation vary between 700 and 800 TPD (Sharma 2016, Katiyar et al. 2013, Dasgupta 2016) which due to different time horizons may well represent the increase in waste generation. Compared to 550 TPD reported in BMC (2006), the increase would at least amount to about 30% in the last decade.

Data on waste composition are available from BMC but date back to 2006. A more recent source presenting the waste composition for 2009 (Katiyar et al. 2013) was taken as basis for the GHG calculations. The composition describes samples of Bhopal's residential MSW as listed in Table 6. The main waste fractions are biodegradable materials. The recyclable dry waste fractions paper, plastics, textiles, metals makes up about 20% of the total waste. The share of fine earth dust is assumed to originate from unpaved areas.

Table 6: Waste composition of samples from Bhopal, 2009

Waste fractions and characteristics of MSW	[% of weight]
Food and fruit waste	43.18
Garden trimming	3.06
Hay, straw and leaves	22.15
Paper and cardboard	11.06
Rubber, leather	0.13
Plastics, including polythene	5.72
Textiles	1
Wood	0.5
Glass, crockery	1.1
Tin cans	0.49
Stones, bricks	0.6
Coal ash, fine earth dust	9.59
Ferrous metals	0.87
Non-ferrous metals	0.21
Other waste fractions	0.26

Source: (Katiyar et al. 2013)

5.2.3.2 Collection and treatment

According to the BMC website (2017), D2D collection started in every ward in August 2013. Segregated collection was done in one ward as pilot project. Nowadays, collection is well implemented by the Health Department, BMC in the city, with a significantly improved efficiency over the last five years (Sharma 2016). But to date MSW from households and commercial centers is usually unsegregated when collected. The waste collected is unloaded at one of the more than 3,000 collection bins/centers and then transported to the Bhanpura dumpsite (CDIA 2015).

Figure 12: MSW transported to Bhanpur dumpsite and weigh bridge

Photos by ifeu

The Bhanpur dumpsite is the major disposal site in Bhopal and is in use for over 35 years. Meanwhile it has reached its capacity (BMC 2014), and is also lying inside municipal limits (see Figure 11). As a result, the dumpsite is intended for closure. Transport to the dumpsite takes place with different garbage trucks and is weighed before disposal (Figure 12). Digital data recording was implemented approximately at the end of 2016. The data serve for documentation purposes (Tiwari & Rupali 2017).

The dumped waste is piled up not higher than 5 m, and is neither compacted nor covered. Some recyclable plastics material that is financially beneficial is extracted and sorted in a nearby sorting unit by the informal sector. Some dumped waste is digged out and treated in a nearby mechanical treatment plant to regain space and in the hope to produce salable manure from the processed material. Figure 13 from top left to bottom right shows (1) the MSW dumped, (2) the cut for digged out material, (3) processing of digged out material, (4) the packed processed product.

Figure 13: MSW dumped and waste to fertilizer unit at Bhanpur dumpsite

Photos by ifeu

Here, like in Bangalore, the MSW consists of textiles and other ropelike material which is likely to cause similar problems in mechanical treatment facilities. Compared to fresh MSW the digged out material is easier to be mechanically treated. However, the fertilizer produced from the dumped waste was analyzed once with the result of rather poor nutrient content. Due to this selling of the manure is difficult and it is mostly stored in the storage area of the facility. (Khare 2017)

Recyclable plastic picked out from the dumped waste is sorted further in a nearby plastic sorting unit where the plastic waste is presorted for further processing like crushing or extrusion at another place. Derived products from processing are shown in Figure 14. Granulates are produced from milk pouches or other high quality plastics, small shreds are used for road construction and fluffy material for co-incineration in cement kilns.

Figure 14: Plastic waste sorting center nearby dumpsite

Photos by ifeu

For the status quo scenario only 100% unsegregated collection and dumping of the MSW was taken into account because the other activities are either very specific (fertilizer from waste) or no waste data on city level is available (informal recycling).

5.3 Haridwar

The city Haridwar is the capitol of and the largest city in Haridwar District in the North Indian state Uttarakhand. Haridwar is one of the seven sacred cities of Hindu culture in India and one of the four places in India where the Kumbh Mela – the largest Hindu pilgrimage of faith – takes place every twelve years.

5.3.1 Geography and climate

Haridwar is located at the Ganga river where it enters the North Indian River Plain after flowing down the Himalaya. At an altitude of about 300 m above sea level, the city spreads over about 12 km^2 on both sides of the river Ganga with the main area situated northwest of the river.

According to the Köppen Geiger climate map (Peel et al. 2007), Haridwar is located in a region classified as "Cwb", but near to "Cwa" climate zone. The main climate is temperate (C) with dry winters (w) and warm (Cwb) to hot (Cwa) summers with monsoon influence. Haridwar's climate is seasonal with winter season from November to February, followed by an early summer season from March to June and then a monsoon season from July to September. Humidity during summer is stated as 40 to 60% and the annual maximum temperature as 30 to 42°C, whereas in winter the humidity declines to 25% and temperature can decline to a minimum of 4°C. During rainy season the humidity is 70 to 85%. In summer hot dust raising winds with velocities of up to 15 km/h occur frequently. (GHK 2007)

5.3.2 Population and city structure

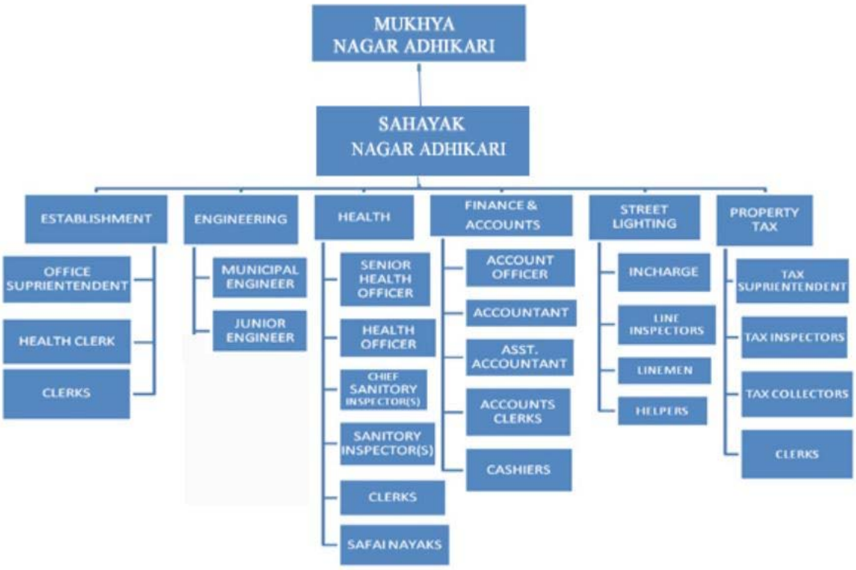
As per census of India 2011 Haridwar city has a population of about 230,000 people (ORGI 2015). However, the city's floating population (tourist, worshippers) is up to about 160,000 people per day (IPE 2009, CPCB 2016). The city's population has been increasing for decades, and current projections estimate a population of about 293,000 for 2025 (MoUD 2016) and 424,000 people for 2041 (Urban Development Directorate of Uttarakhand 2015). A considerable proportion of the population is living in slum areas. (IPE 2009) mentions 86,888 slum dwellers and (MoUD 2016) states 56,295 people living in slum areas in 2011.

In 2016, the city was divided into 30 wards, aggregated in 4 zones (CPCB 2016). Haridwar's outskirts are among the most industrialized regions of Uttarakhand with Bharat Heavy Electricals Ltd. (BHEL) alone employing several thousand workers (IPE 2009).

5.3.3 Municipal solid waste management

The municipal authority in Haridwar is called Nagar Nigam Haridwar (Figure 15). "Mukhya Nagar Adhikari" roughly translates to "Chief Municipal Officer", and the department of Nagar Nigam Haridwar responsible for solid waste management is the health department. For some duties (such as D2D collection of MSW) Nagar Nigam Haridwar has contracted private sector organizations.

Figure 15: Organization structure of Nagar Nigam Haridwar



Source: (Nagar Nigam Haridwar 2017)

Waste management in Haridwar is challenged by the high floating population, and some rules and requirements are specific for places like Haridwar. In reaction to the huge amounts of plastic waste accumulated on the riverbanks, the National Green Tribunal (2015) prohibited the use of plastic for serving food, commodities and packaging in the entire city of Haridwar and especially near the river Ganga in July 2015. However, in August 2016, plastic in form of bags, plates and alike was still openly and frequently used in Haridwar (Trivedi 2016). Sensitizing of pilgrims was deemed insufficient and in the seven months the Haridwar Municipal Corporation had confiscated 76 kg of polythene and fined different traders 250,000 rupees.

5.3.3.1 Waste generation and composition

Available data on MSW generation vary between about 200 and 400 TPD (Urban Development Directorate 2015, MoEF 2015, Nagrath 2016). <u>For the GHG calculations in this study, the average MSW generation is assumed to be 237 TPD</u>, including an estimated waste generation of 315 TPD during 20 days per year due to religious festivities (Nagar Nigam Haridwar 2015). Projections for MSW in Haridwar expect 278 TPD in 2025 (MoEF 2015) and 368 TPD in 2041 (Urban Development Directorate 2015).

Data on waste composition are available from three different sources (IPE 2009, Sharma et al. 2010, Jain & Sharma 2011). Although, (IPE 2009) refers to the years 2007/2008 it was used for the GHG calculation, because it is more comprehensive than information from the other sources. Sharma et al. (2010) reports only shares of organics and recyclables from door-to-door samples, while Jain & Sharma (2011) only analyzed small samples taken from a dumpsite. The waste composition given in (IPE 2009) is presented in Table 7. Further details on waste composition from the other sources are described in the report for Haridwar (separate Annex to this report).

Table 7: Waste composition of samples from four wards arriving at disposal site

Waste fraction	[% of weight]	Details
Biodegradable Waste	50.35	Mostly kitchen waste (35.10), green leaves (7.46), dry leaves (4.17), straw/hay (1.50), vegetables (1.65), flowers (0.21), dead animals (0.26)
Paper	5.08	
Plastic	8.40	PE bags (7.13) and plastics (1.27)
Textiles	9.60	
Glass	0.12	
Inerts	23.91	Sand/earth/soil (19.95) and construction & demolition waste (3.96), which was made up of stone, lime, bricks and ceramics
Metals	0.06	
Wood	0.38	
Others	1.24	Rubber/leather (0.53), school bags (0.5), thermocole[1)] (0.18) and human hair (0.03)

Source: (IPE 2009)
1) Indian term for polystyrene

5.3.3.2 Collection and treatment

According to (MoUD 2016) 170 TPD out of the 237 TPD are collected in Haridwar, which corresponds to a collection rate of about 72%. The remaining waste is non-collected, scattered waste. MSW is collected from households in residential areas as well as from slum areas. D2D collection from households was commissioned to the private company KRL Waste Management (Haridwar) Private Limited, which provided source segregated D2D collection in 22 of the total 30 wards in early 2017, and collects a total of 110 TPD. In the other wards still unsegregated collection was done by the municipality (CPCB 2016, HMC 2016 & 2017). <u>These figures for collection are used for the GHG calculation scenarios.</u>

For D2D collection, waste generators are asked to segregate biodegradable waste and non-biodegradable waste (including recyclables). Source segregation was started although the MSW facility intended for treatment of the biodegradable waste was still under construction. D2D collection is provided daily using bicycle rickshaws with several bins for segregation (Figure 16). Altogether, approximately 110 collectors visit about 200 households each.

The collected waste is transported to a community container (waste storage depot) where the collector manually extracts salable recyclables, whereas the remaining waste (wet waste as well as the remaining dry waste) is deposited in the community container which is finally transported for disposal to the dumpsite.

Figure 16: Door-to-door collection by bicycle rickshaw in March 2017

Photos by ifeu

Non-collected waste is basically scattered onto the streets or into open sewers. Especially the latter have the potential to be washed out into the Ganga river and to increase marine littering. Street sweepers are engaged to remove the stuck waste as shown in Figure 17. However, not all washing out can be prevented and the removed material contains a lot of sludge from the open sewer, which adds to the waste amounts and heavily contaminates the dry waste rendering it no-recyclable.

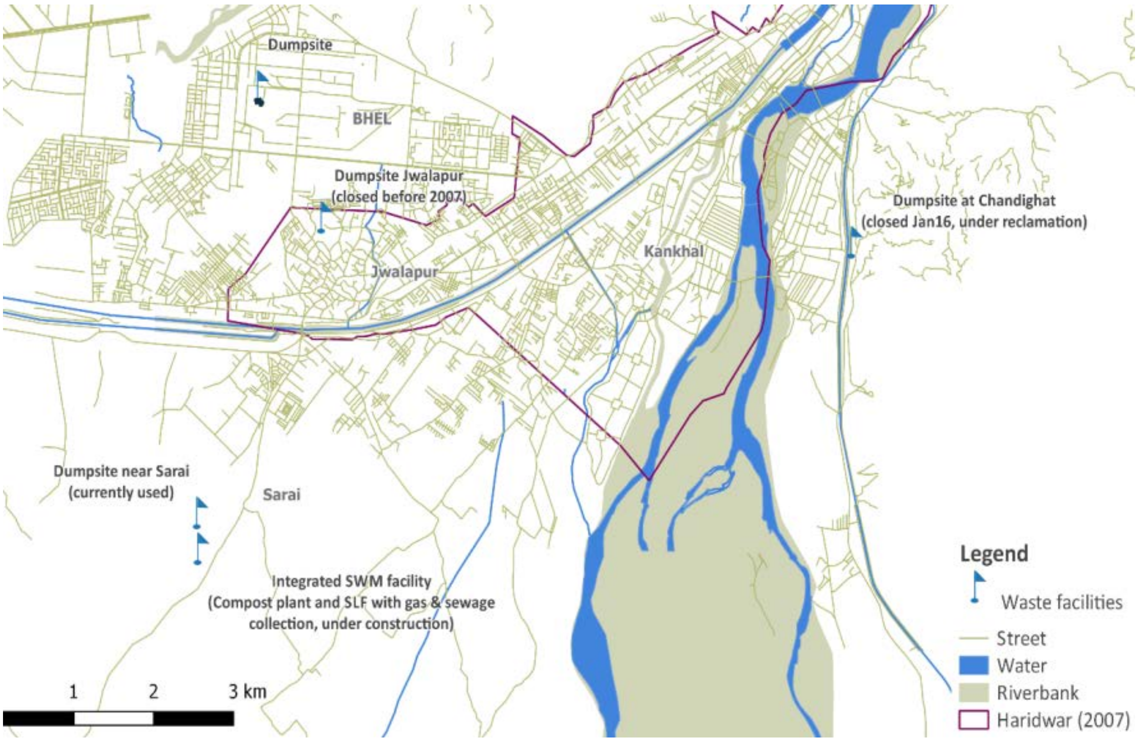
Figure 17: Waste and mud removed from open channels

Photos by ifeu

In 2017, MSW from Haridwar was disposed at a dumpsite near Sarai (see Figure 18). The use of the older dumpsite Chandighat has been forbidden in 2015, and another dumpsite at Jwalapur has been abandoned already before 2007. All of these dumpsites are shallow, not higher than 5 m, and completely uncontrolled. During the visit in March 2017 the dumpsite near Sarai was burning on several locations.

To achieve compliance with the MSW Rules Haridwar planned a new integrated SWM facility, which was partly financed under the JNNURM project. As a public-private partnership, KRL has been contracted to build the facility (Nagrath 2016, HMC 2016 & 2017). The facility will include a sanitary landfill as well as a compost plant and is also located near Sarai.

Figure 18: Waste disposal sites near Haridwar



Cartography: ifeu; municipal boundary based on (GHK 2007); other spatial data based on © OpenStreetMap contributers

The compost plant has been designed for a capacity of 100-150 TPD biodegradable waste during a first phase from 2015 until 2025 and 150-200 TPD during a second phase from 2025 until 2040, while the landfill's capacity is planned to be 50 TPD (MoEF 2015, CPCB 2016). Recyclables are meant to be collected separately and recycled, thus leaving only separately collected inert materials (mainly soil from road sweeping) for deposition in the landfill. In addition, rejects from the compost plant will be deposited at the landfill (IPE 2009). During the visit in March 2017, the composting plant was still under construction. The picture on the left in Figure 19 shows the concrete covered windrow and drying area and the roofed process shed in the back. On the picture on the right the constructed mounts for machinery can be seen, which was planned to be installed a week later.

Figure 19: State of construction of the compost plant in March 2017

Photos by ifeu

The construction of the integrated SWM facility has been delayed due to lack of sufficient funding. The JNNURM project ended in March 2015, when not even half the funds for Haridwar's project had been dispersed. Most of the funding dispersed had been used to buy equipment for collection and transport of waste. Since then Uttarakhand's state government has provided some further funding for the project (Nagrath 2016).

6 Summary observations and conclusions for scenarios

Literature review as well as visits and interviews in the 3 cities reveal that waste management in India still is a huge challenge. There are many very good initiatives on grass root level ranging from NGO activities to other private or voluntary initiatives like "I got garbage". But continuously growing waste amounts and changes in waste composition due to population growth and migration into cities as well as a rapid change in life style pose major difficulties.

6.1 Observations and challenges

In summary, the research project observed the following during the information gathering phase 2016/2017.

First of all, data and information are not easily available, if at all:

- Data are not available on an aggregated level;
- different sources estimate different amounts of waste generated, and the fate of the waste is partly not known;
- data and information on MSW, which is generated by bulk generators, and collected, treated and disposed by contracted service providers, are not recorded on municipal level, though these data are principally available at the level of the contractor;
- no informal collection and recycling are recorded on municipal level, though information is to some extent available;
- digital recording of collected data at treatment sites and reporting to the municipality has started, but no information was available on how and at which level these data are compiled and what purposes they are used for;
- data on waste composition or characteristics is available from a few studies, which are partly outdated (published about 10 years ago) and not representative because only a few small one-time samples were taken;

Secondly, waste collection and treatment in the 3 cities as well as recycling and recovery operations are applied, however:

- Relevant amounts of MSW are still not collected especially in Bangalore and Haridwar;
- in all 3 cities (partly in Bangalore), collected waste is still disposed of in an unsanitary manner;
- source segregation has generally started, but MSW facilities to receive this waste were either not yet in place or not properly operating;
- segregation at household level especially of wet waste (defined as biodegradable waste) was observed to be hard to implement and still rather poor. The wet waste fraction still consisted of plastics, textiles, and other non-organic waste;
- this wet/mixed waste delivered to mechanical-biological treatment plants in Bangalore contained long rope-like textile material or ornamental decorative appliances that regularly clogged the trommels and prevented proper separation of a RDF and organic waste stream, resulting in poor quality products;
- other waste fractions like thermocole (polystyrene) and packaging waste, especially lightweight plastic bags, cause problems as they are difficult to recycle and basically end up at unmanaged disposal sites;

- thicker plastic waste of higher value are informally collected also from disposal sites and are granulated and sold as secondary product or shredded and used for road construction. Some plastic waste is processed to RDF for co-incineration;
- recycling activities are reserved to informal recycling which has a long tradition in India, including D2D collection of recyclables, sorting and trading of secondary raw materials. Informal recycling is well-organized and market oriented, but underlies partly unhealthy working conditions.

Thirdly, observed administration and policy challenges are:

- a high staff turnover, especially observed in Bangalore, makes it difficult to consistently execute waste management plans;
- lack of capacity at municipal level is still one obstacle to implement integrated SWM systems;
- the assignment of more responsibility to the waste generators like bulk waste generators or decentralized private initiatives helps to relieve overloaded municipalities to some extent,
- but the lack of available data and/or a monitoring system for all MSW streams makes it difficult to assess or plan proper waste treatment capacities.

The factors mentioned have an impact on the accuracy of the GHG balance for the status quo and the optimization scenarios. It is obvious that waste data is of major importance, not only to estimate the potential for GHG mitigation from the waste sector. Therefore the status quo and the scenarios had to be based on various assumptions. The impact of data on the GHG-mitigation potential is further illustrated in chapter 9.

6.2 Conclusions and assumptions for scenarios

The status quo scenario for the 3 cities is based on the observed treatment practices as described in chapter 5. Data on waste composition is taken from the available literature data reported, although not representative. This data is needed (1) to calculate the relevant waste characteristics like carbon content and heating value, and (2) to examine the potential value in MSW. The share of recyclables, organics and others in MSW is used to derive waste treatment possibilities for the optimization scenarios.

6.2.1 Terms and definitions

In general, some definitions and aspects need to be clarified for a common understanding of the scenarios.

1. The observations regarding waste segregation into the legally defined categories dry and **wet waste** showed significant shortfalls in 2016/2017. To illustrate the potential and limits for a better segregation the term wet waste is here further specified to

- wet/mixed waste
- wet/source segregated organic waste

"Wet/source segregated organic waste" is only used when almost pure organic waste is referred to, and "wet/mixed waste" if the waste showed the characteristic of mixed waste as was the case in Bangalore and Haridwar.

2. In India the term **composting** is often used indifferent if the treatment of wet/source segregated organic waste is addressed or of wet/mixed waste. To avoid misunderstandings we distinguish the following terms in the scenarios

- composting plant
- mechanical-biological treatment plant (MBT)

"Composting" exclusively addresses the treatment of wet/source segregated organic waste, while the term “MBT” is used for the treatment of “wet/mixed waste”.

3. In India, anaerobic treatment of waste is called “**biomethanation**”. This term is used in the status quo scenario for the existing treatment as described in chapter 5. In the optimization scenarios anaerobic treatment of wet/source segregated organic waste is also considered as an option. However, this treatment addresses modern digestion plants with reduced diffuse methane emissions, efficient biogas yield and composting of the digestate producing high quality compost. This treatment is called “**anaerobic digestion** (AD)” in the optimization scenarios.

4. Outputs from MBT are typically RDF, compost and inert material. In the case of the MBTs visited in Bangalore, RDF and compost, both were of low quality due to shortages in separation. Therefore, in the **status quo scenario** the following terms are used for the **MBT output**:

- “RDF, low quality”, which is stored in the RDF storage or disposed of
- “compost, low quality”, which is hardly marketable
- “solid residue, stabilized” and “inert”

The “RDF, low quality” still contains a considerable fraction of organic material and disposal of this fraction is combined with methane generation. “Compost, low quality” is considered to be mature but of low nutrient content and potentially contaminated with pollutants as derived from mixed waste. Therefore, no benefits are attributed to this compost. “Solid residue, stabilized” refers to matured organic material which is separated from the low quality compost. This output fraction is disposed of and still generates methane emissions but to a much less extent than non-matured organic material. “Inert” refers to sand and other inert material which is not biodegradable and thus does not generate methane emissions from landfilling.

In the **optimization scenarios** proper mechanical-biological treatment of wet/mixed waste is assumed with the following **MBT outputs**:

- “RDF, high quality”, which is assumed suitable for co-incineration in cement kilns
- “RDF, mean quality”, which is assumed to be of somewhat less quality due to lower heating value but still suitable for incineration
- “solid residue, stabilized” and “inert”

The latter two are characterized in the same way as in the status quo scenario. No compost output is assumed because compost from mixed waste would be of low quality.

5. In the optimization scenarios the term “**compost**” refers to marketable high quality compost derived from composting and/or anaerobic digestion plus composting of wet/source segregated organic waste.

6. **Waste incineration** is considered as an option for certain waste streams in the optimization scenarios. Usually, MSW in India has a high organic content (cf. Kumar et al. (2009)) and partly also a high inert fraction which both indicate that a self-sustaining combustion reaction cannot be obtained from a majority of MSW, and auxiliary fuel would be required to aid waste combustion. MSW incineration plants for example in Germany typically operate MSW with an average heating value in the range of 8-14 MJ/kg. So-called Waste-to-Energy (WtE) plants also operate with a higher average heating value, although the technology is the same.

In case waste incineration is addressed in the optimization scenarios it is basically not assumed that one of the cities shall or can build an own incineration plant as suitable waste streams are likely to be too small to install economically viable plants. The only exception is scenario 2b for Bangalore. Otherwise rather two alternative possibilities are assumed:

a) Incineration of source segregated combustibles or of residual wet/mixed waste in a so-called "**cluster WtE**". This term refers to a cooperation concept of several cities as realized for example with the WtE plant in Jabalpur. A cluster WtE derives waste not only from one city but from several cities. The specialty is that the delivered waste consists only of source segregated MSW fractions which are suitable for incineration. As an alternative to city cooperation sufficient combustible waste throughput could also be derived by acquisition of combustible waste from other sources like industrial or commercial waste.

b) Co-incineration of "RDF, mean quality" as well as impurities or rejects separated from wet/source segregated organic waste and from dry waste in a **WtE plant** which typically processes e.g. agricultural residues. Such plants are more frequent in India than MSW incineration plants. In addition, also co-incineration in an existing cluster WtE may be feasible. In both cases cities would need to disburse for respective incineration capacities.

In the GHG calculation the efficiency of energy generation for the cluster WtE and/or WtE plants is considered as equal to the current average efficiency of MSW incineration plants in Germany/Europe, with an electrical net efficiency of 12% and a thermal efficiency of 30%.

6.2.2 Scope and scenario development

The **scope** of the GHG calculation scenarios is focused on **MSW from households in the responsibility of the municipality**. Neither MSW from bulk generators nor MSW treated by the informal sector are included because neither sufficient data on waste amounts nor on treatment routes was available.

The **status quo scenario** is based on the waste streams derived from the municipalities and other sources. The waste composition is taken from the available literature data reported in Table 5 for general Bangalore, in Table 6 for Bhopal and in Table 7 for Haridwar. The most important aspects for the status quo scenarios of the 3 cities are presented in Table 8.

Table 8: Overview status quo scenario and main parameters for the 3 cities

	Bangalore	Bhopal	Haridwar
MSW generated	4000 TPD	800 TPD	237 TPD
Collection rate	80%	100%	72%
Source segregation started	yes	no	yes
Treatment of collected MSW	25% DWCC, 72.5% MBT, 2.5% biomethanation	100% unsanitary disposal	100% unsanitary disposal
Main fractions waste composition:			
Organic waste (food, green waste, hay, straw, wood)	59%[1)]	69%[2)]	50%[3)]
Recyclables (paper, plastic, textiles, glass, metals)	33%	20%	23%
Inert (sand, silt, debris)	5%	10%	24%
Waste parameters for MSW generated calculated from the waste composition			
Heating value [MJ/kg]	7.6	5.8	6.3
Fossil carbon [% mass]	6.8%	3%	5.6%
Regenerative carbon [% mass]	16.4%	17.1%	13.5%

1) 53% organic and vegetables + 6% wood (Table 5)
2) rounded value from food and fruit waste, garden trimming and hay, straw, leaves and wood from Table 6
3) rounded value from biodegradable waste (except dead animals) plus wood from Table 7

From the available information on MSW generation the upper value is used for the status quo scenarios for Bangalore and Bhopal. The value for Haridwar includes the estimated waste generation due to religious festivities. The waste composition of the cities reveals a comparably high share of organic waste in Bhopal, and a comparably high share of inert waste in Haridwar. Both aspects are considered for the optimization scenarios.

For the **development of the optimization scenarios** the following aspects were taken into account:

- Principally, the scenarios aim at representing integrated waste management systems with potential co-benefits for GHG mitigation;
- they consider the different settlement structures of the 3 cities as well as existing approaches, plans and regulations to be as realistic as possible;
- the GHG mitigation potential is based on achievable and realistic technologies applied and operational conditions fit to achieve the necessary quality of the output materials;
- the potential share of waste to recycling, waste for composting or waste for incineration is based on the waste composition of the status quo (prerequisite LCA method);
- the GHG mitigation potentials shown are not the maximum possible, but the realistically achievable in the nearer future.

Altogether 2 optimization scenarios are developed as a step by step approach which means that the scenario 1 is the first step to a further optimized scenario 2. This does not mean that the development of the waste management system could or should stop at this point. Integrated waste management systems can provide further optimization potentials. However, due to the before mentioned criteria feasible scenarios were developed instead of ideal ones.

Landfill gas collection is not an option. On the one hand landfilling of non-treated usable waste is actually not allowed since 2000 according to the SWM Rules (MoEF 2000, 2016). Although still considerable waste amounts are disposed of at unsanitary landfills, ULBs are struggling to implement compliant treatment options. On the other hand existing landfills are hardly suitable for the subsequent installation of a gas collection system. They are either mostly unmanaged and more or less shallow like in Bangalore, Bhopal, or Haridwar or they are very steep due to space scarcity as observed for example in New Delhi. In addition, the waste disposed of at the landfill in New Delhi seemed very dry and inert. It is assumed that gas generation is happening more rapidly than usual. In any case a test field for gas collection at this disposal site was given up due to a low gas yield.

7 SWM scenarios and GHG calculation

In the following the developed SWM scenarios are presented as well as the results of the GHG calculations. Prior to the GHG results general assumptions for the calculations are explained.

7.1 SWM scenarios

The developed scenarios are described briefly and are illustrated in so-called Sankey-diagrams. Sankey-diagrams show mass flows in a proportional way. That means the width of the arrows corresponds to the masses behind. **In the Sankey-diagrams the following main color codes are used:**

- brown: MSW, not collected, unsegregated or poorly segregated wet/mixed and dry waste
- green: wet/source segregated organic waste and compost
- yellow: source segregated dry waste and recyclables

7.1.1 General assumptions for the scenarios

The most relevant assumptions for the status quo scenarios are briefly repeated in the chapters for the cities. Here some common assumptions are explained.

In all status quo scenarios MSW is partly or completely disposed of at unsanitary landfills. From the visits in 2016 and 2017 **landfill fires** were observed in Bangalore (wild dumps on the road sites) and in Haridwar (dumpsite Sarai). Although this was not the case in Bhopal, 10% landfill fires are assumed equally for all status quo scenarios where MSW is disposed of at unsanitary disposal sites.

General assumptions for the two optimization scenarios are given in Table 9. The optimization scenarios are developed following the criteria described in chapter 6.2.2. A basic aspect on the way to an integrated waste management is the implementation of proper waste collection. In addition, source segregation is considered as a key element to achieve operational waste treatment and quality products. Purely segregated waste fractions are prerequisite to produce quality products. From experience in Germany it is feasible to achieve purely segregated waste fractions from source segregated collection with only a small share of remaining impurities (about 5%). Although, this needs educational and counseling services for the citizens as well as respectively trained waste collectors, it is assumed easier to be implemented in E+D-countries like India than technical solutions. In addition, any high-tech sorting solutions would only be feasible for dry recyclables. Here further improvement may be possible for example by the installation of automatic sorting units in a so-called material recovery facility (MRF). However, organic waste must be collected separately and not mixed with other residual waste as this would pollute the organic fraction irreversibly.

Therefore, already for scenario 1 not only 100% collection rate is assumed but also improved source segregation to a moderate extent. In general, source segregation of wet/organic waste allows producing high quality compost which is assumed to be used in agriculture. Source segregation of recyclables allows higher recycling rates and deliverance of low quality waste or non-recyclable waste is avoided. Especially for Bhopal source segregation of combustibles is assumed as it was learned from interviews that Bhopal is considering the implementation of a cluster WtE concept in cooperation with other cities.

Table 9: Overview assumptions optimizations scenarios

Scenario 1 (1st step)	Scenario 2 (2nd step)

• 100% collection rate
• (improved) source segregation
   • of wet/organic waste producing high quality compost in Haridwar, partly in Bhopal and Bangalore
   • of recyclables in Haridwar and Bhopal; in Bangalore of dry waste with optimized sorting (e.g. MRF)
   • of combustibles in Bhopal sent to a cluster WtE ("Jabalpur concept")
• optimized treatment of remaining wet/mixed waste, problematic fractions manually or technically separated producing high quality RDF for co-incineration and RFD for WtE
	• in Bhopal and Bangalore increase of source segregated wet/organic waste: 70% composted, 30% anaerobic digestion (AD) -> remaining waste fraction reduced and less wet
	• for Bangalore additional scenario 2b with cluster WtE for wet/mixed waste instead of improved MBT
	• in Haridwar exclusion of inert (silt) from MSW stream through optimized D2D-collection leading to:
	   • increase of recycling
	   • reduction of litter spots
	   • minimization of marine littering

For the remaining residual wet/mixed waste mechanical-biological treatment is assumed because this kind of treatment is best accepted in India. To avoid clogging of the trommels as observed in Bangalore problematic waste fractions may be removed either manually – if possible best already with source segregation – or by technical solutions. This allows proper separation of RDF and an organic fraction. The thus separated RDF can be further processed for co-incineration in cement kilns or WtE-plants. The organic fraction can be stabilized by biological treatment. Although the stabilized solid residue is not suitable for quality compost its disposal is combined with considerably reduced methane generation compared to disposal of untreated organic waste. In Haridwar the MSW facility under construction can be used to treat both the source segregated wet/organic waste and the wet/mixed waste in a 2 line operation. From the dimensions of the facility there is enough space to do so but it has to be made sure that the two waste streams get not intermixed. Therefore, the mechanical pretreatment is reserved for the wet/mixed waste to remove recyclables. The purely source segregated wet/organic waste is composted directly.

For the scenario 2 the efforts for source segregation of wet/organic waste are increased for Bhopal and Bangalore. In addition, this waste stream is partly anaerobically treated in modern low emission anaerobic digestion (AD) plants. Thus not only compost is produced but additionally the energy content of the organic waste is used producing biogas for energy generation in combined heat and power plants (CHP). For Bangalore two alternative scenarios are considered, scenario 2a where the remaining residual wet/mixed waste is still treated in a MBT, and scenario 2b where instead of that this fraction is incinerated in a WtE plant. The scenario 2 for Haridwar takes into account the comparably high share of inert material in the waste composition. This is resulting from silt in open sewers which is mixed with scattered waste and dig out again. In scenario 2 the exclusion of this silt material is assumed through the assumption of 0% scattering. Thus not only litter spots are avoided and the recycling rate is increased but also, and most importantly, marine littering is prevented.

In all cases the assumed mass flows for the optimization scenarios are derived from the waste compositions for the 3 cities and respect the properties of the waste. The Sankey-diagrams for the scenarios are presented in the following chapters for the 3 cities.

7.1.2 Bangalore

The status quo scenario is based on the data and information gathered in 2016/2017. The most relevant aspects are (see also underlined passages in chapter 5.1.3):

- Waste generated: 4000 TPD (upper value for MSW from literature)
- 20% non-collected waste, thereof 90% dumped, 8% open burnt, 2% home composted
- 80% collected waste, thereof 25% dry waste and 75% wet/mixed waste
- DWCC: 30% not accepted and dumped, 70% treated, output: 80% recyclables sold to recycling market and 20% rejects to disposal
- MBT: 10% not processed and dumped, 90% treated, output: 20% low quality RDF, 20% low quality compost, 15% stabilized solid residues, 10% inert, 35% losses, outputs are basically stored or dumped, compost is partly sold at a low price
- Small-scale biomethanation plants are included but no benefit is calculated
- Small-scale composting operated by NGOs are not included because this is not within the scope
- For MSW disposed of at unsanitary landfills 10% landfill fires are assumed

The Sankey-diagram for the status quo scenario is shown in Figure 20. The Sankey-diagrams for the optimization scenarios are presented in Figure 21 to Figure 23. For scenario 1 the moderate increase of wet/source segregated organic waste is obvious which is assumed to be 15% of the waste generated. In scenario 2 (both a and b) an increase to 40% source segregation of wet/organic waste is assumed with 70% composting and 30% anaerobic digestion of this waste stream. Additionally, the 100% collection rate and improved source segregation of dry waste is reflected by the yellow arrow in scenario 1, which is assumed to be 25% of the waste generated, and is not changed in scenario 2. The improvements in collection and segregation of waste lead to a reduced wet/mixed waste fraction already in scenario 1 with 60% of the waste generated, which is further reduced to 35% in scenario 2.

Figure 20: Sankey-diagram status quo Bangalore

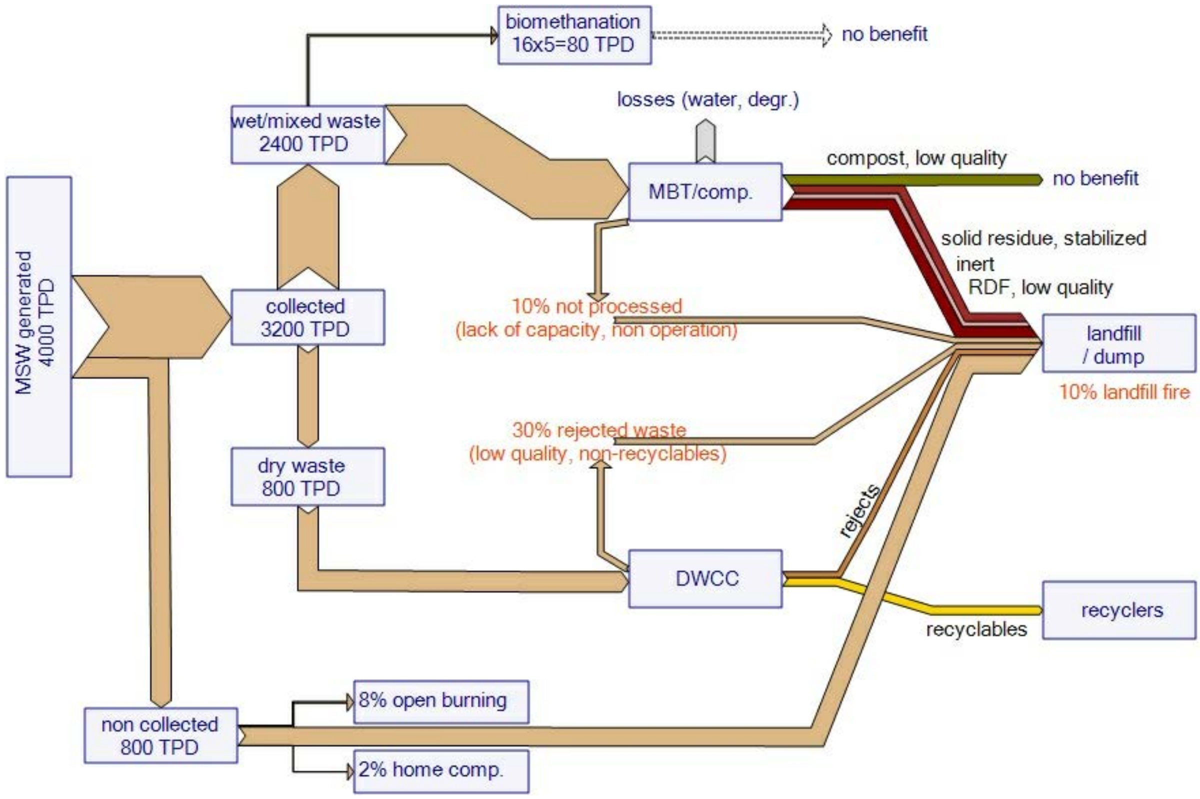


Figure 21: Sankey-diagram scenario 1 Bangalore

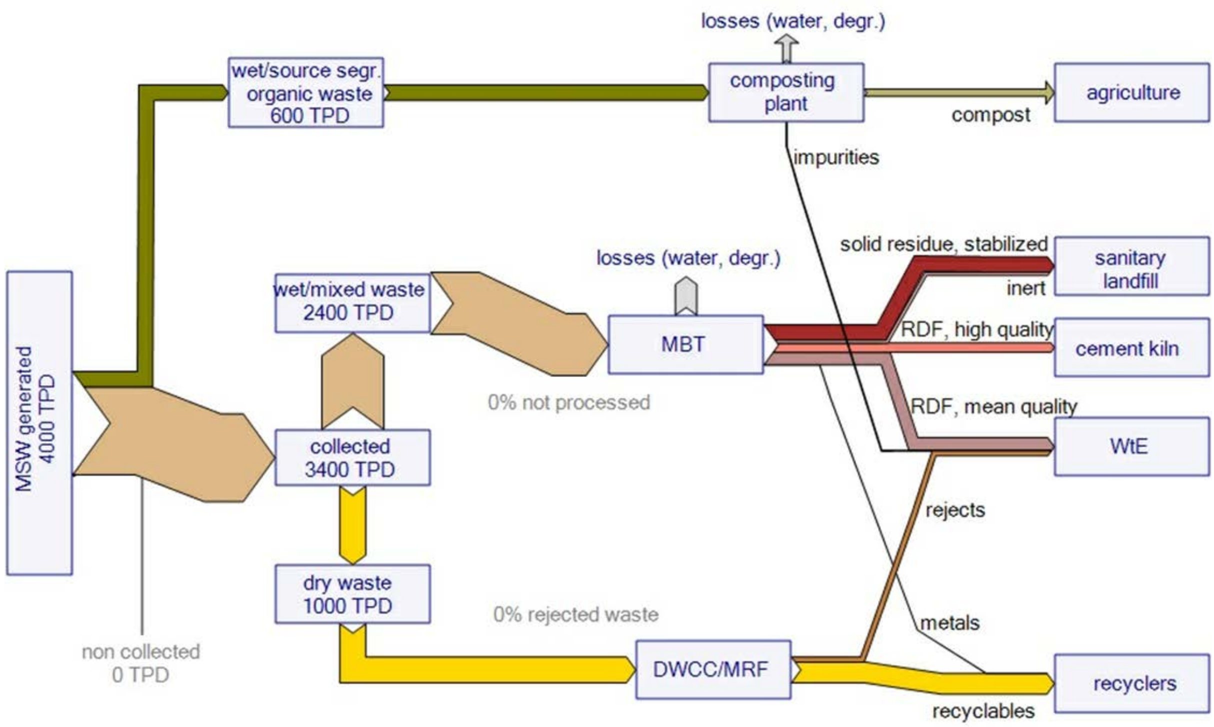


Figure 22: Sankey-diagram scenario 2a Bangalore

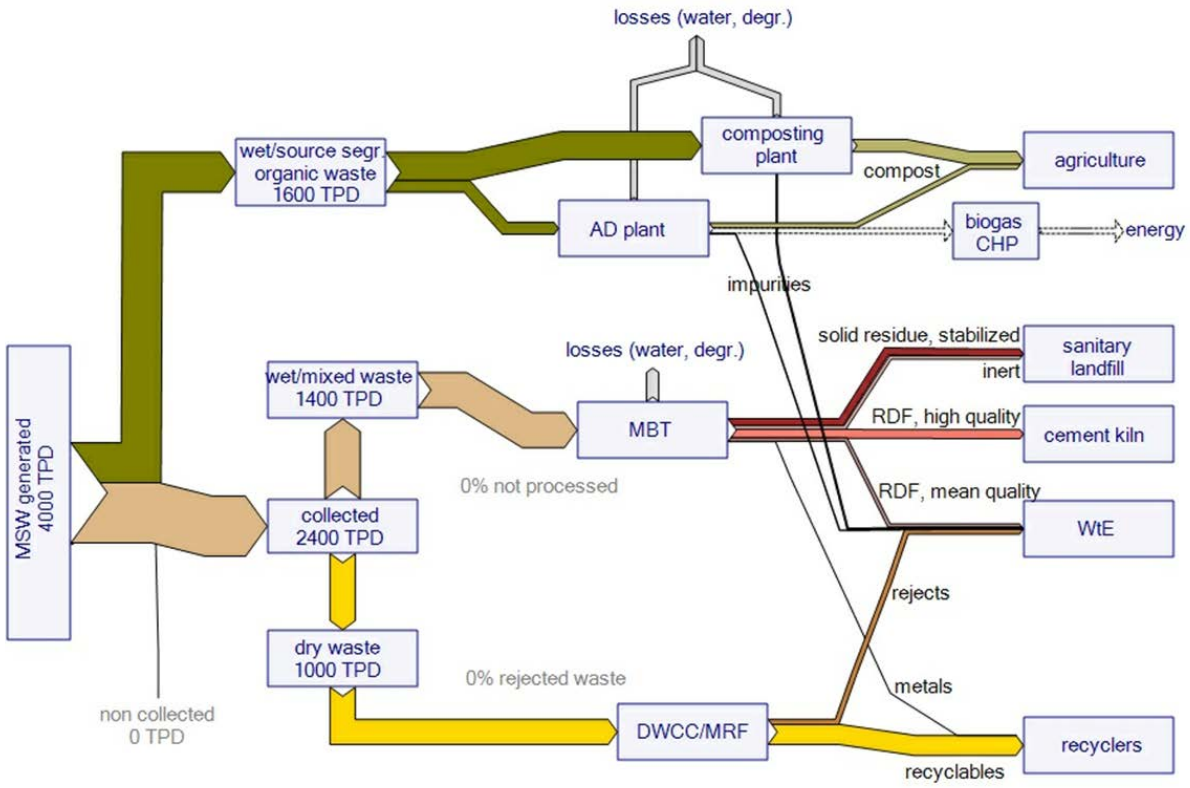
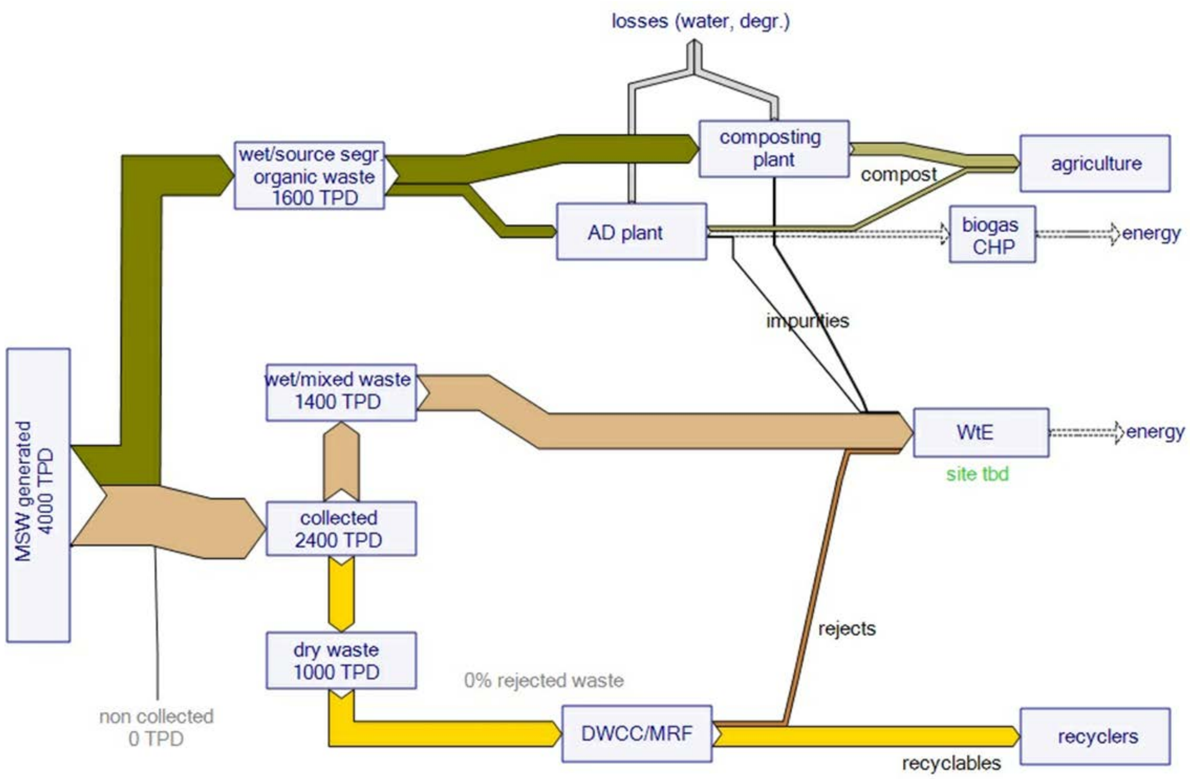


Figure 23: Sankey-diagram scenario 2b Bangalore



The improvement of the MBT operation leads to the production of RDF suitable for incineration and a stabilized solid residue and an inert fraction. In both scenarios 1 and 2a the output proportions are the same with 35% RDF and 30% stabilized solid residue and inert material. Additionally, mechanical separation of 0.3% metals is assumed. The remaining difference to 100% input material results from losses due to water evaporation and degradation of organic material. The difference between scenario 1 and 2a derives from the further increase of wet/source segregated organic waste and a reversely reduced wet/mixed waste fraction. Aside from the absolute values this is reflected in the RDF quality produced which is assumed to be 15% high quality RDF and 20% mean quality RDF in scenario 1, and 25% high quality RDF and 10% mean quality RDF in scenario 2a due to less organic material in the residual wet/mixed waste for scenario 2.

In contrast to scenario 2a the scenario 2b assumes not a mechanical-biological treatment of the remaining wet/mixed waste but incineration in a newly to build WtE plant. The site for this WtE plant may be difficult to determine due to scarcity of space in and around Bangalore which is indicated with "site tbd" (site to be determined) in the Sankey-diagram. In the GHG calculations a transportation distance of 100 km is assumed. With 1400 TPD and/or > 500000 t/a, this waste stream is large enough to operate a new city-owned WtE plant. However, with about 7.4 MJ/kg the calculated heating value of this fraction is on the lower end of typical average values suitable for MSW incineration (8-14 MJ/kg) due to the still relevant share of organic material (about 50%). Nevertheless, scenario 2b is calculated as an alternative because the production of high quality RDF fractions is combined with high sorting efforts and the need of co-incineration capacities. In general, the GHG results can only provide an orientation of the potential GHG mitigation effect as the calculations mainly had to be based on assumptions.

7.1.3 Bhopal

The status quo scenario for Bhopal is based on the data and information gathered in 2017. The most relevant aspects are (see also underlined passages in chapter 5.2.3):

- Waste generated: 800 TPD (upper value for MSW from literature)
- 100% collected waste, 100% mixed waste
- 100% disposal at unsanitary landfill site
- informal activities like plastics recycling or small-scale composting and biomethanation operated by NGOs are not included as not within scope; also the production of fertilizer from disposed of waste is not considered as this is very specific and affects only small waste amounts generated and disposed of in the past
- For MSW disposed of at Bhanpura dumpsite 10% landfill fires are assumed

The Sankey-diagram for the status quo scenario is shown in Figure 24. The Sankey-diagrams for the optimization scenarios are presented in Figure 25 and Figure 26. In scenario 1 it is assumed that source segregation of waste generated can be realized for 30% wet/organic waste, 15% recyclables and 20% combustibles for the assumed cluster WtE. The site for this newly to build cluster WtE would have to be determined ("site tbd"). The transportation distance in the GHG calculation is assumed to be 100 km. Nevertheless, as transport is typically only of minor importance in GHG balances larger distances would not change the results substantially.

The 35% remaining wet/mixed waste treated in a MBT are processed to 20% RDF of mean quality for co-incineration in the cluster WtE and 45% stabilized solid residue and inert material. In addition, separation of 1% metals is assumed which leaves 34% losses. The comparably high share of stabilized solid residue is considered because of the rather high share of organic waste in the waste composition for Bhopal.

The only difference in scenario 2 compared to scenario 1 is an assumed increase of wet/source segregated organic waste to 50% of the waste generated with 70% composting and 30% anaerobic digestion of this waste stream. Thus the remaining wet/mixed waste fraction for MBT is reduced to 15%. Because this waste fraction has a reduced organic content the MBT output is adapted to 30% RDF of mean quality for co-incineration in the cluster WtE and 40% stabilized solid residue and inert material. The metal separation remains 1% of the input which leaves 29% losses.

Figure 24: Sankey-diagram status quo Bhopal

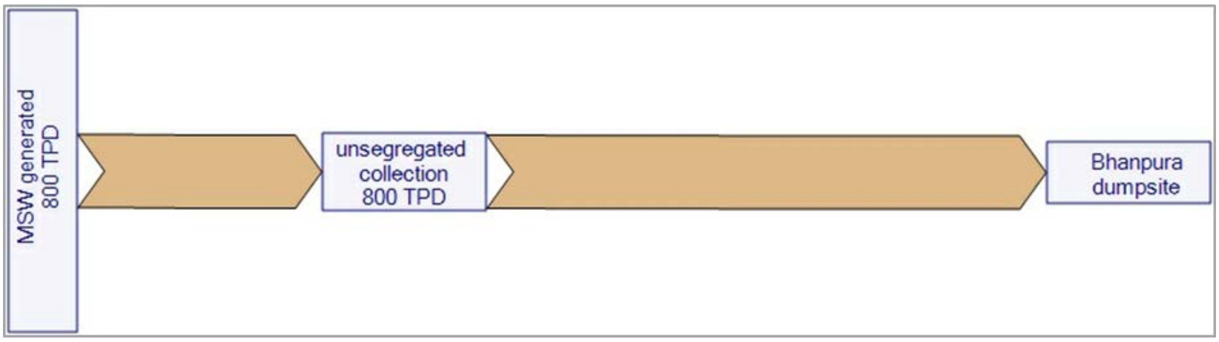


Figure 25: Sankey-diagram scenario 1 Bhopal

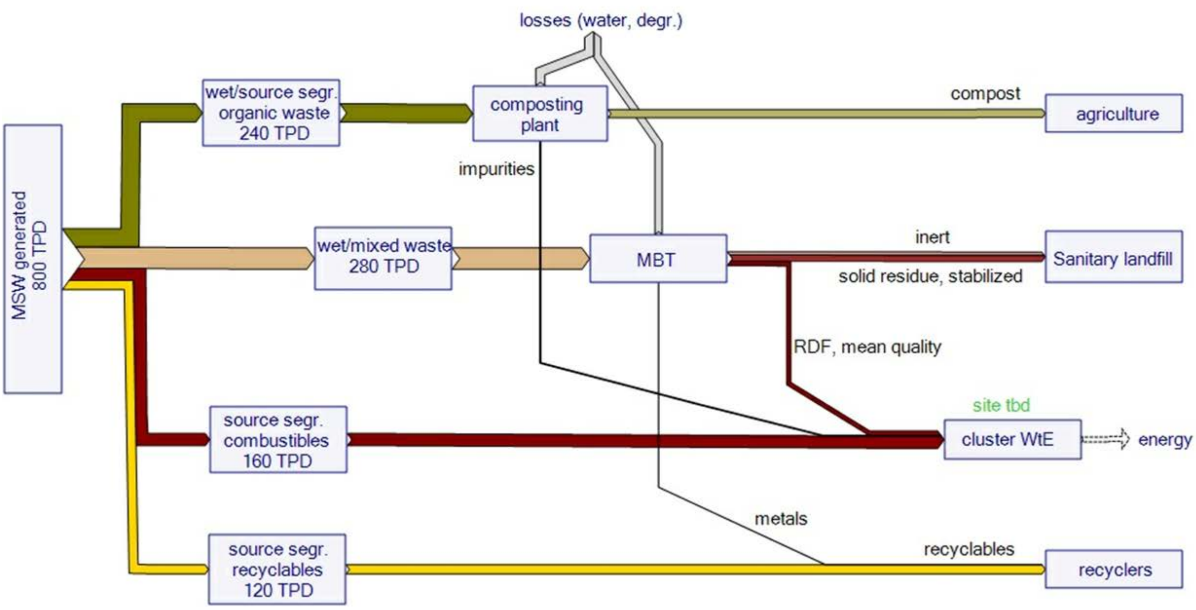
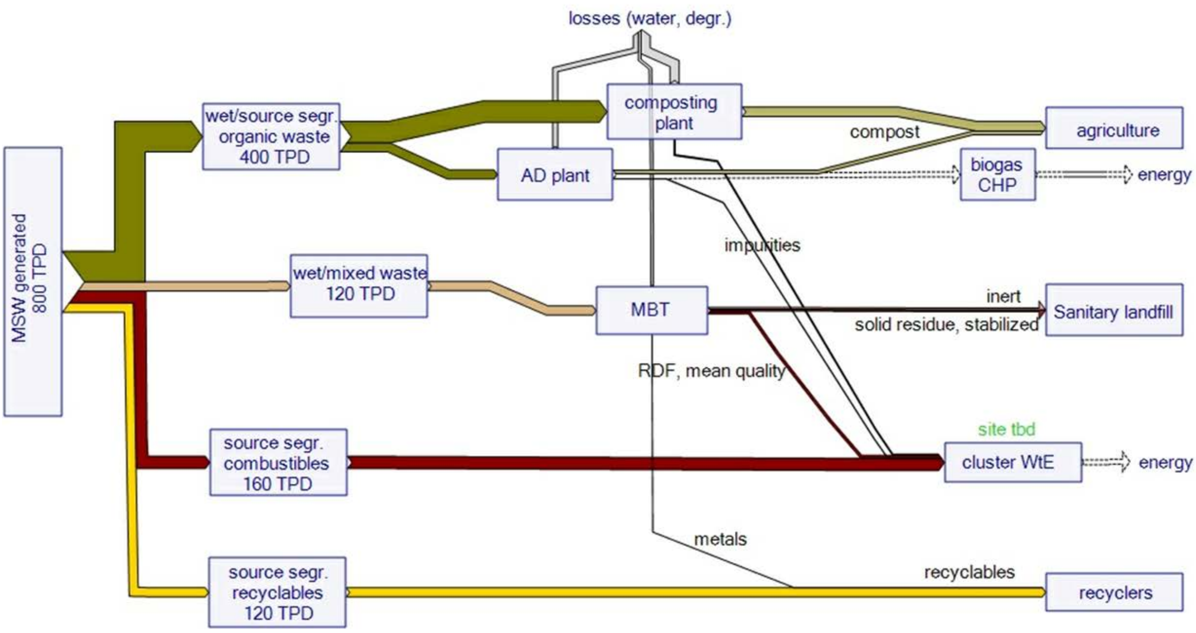


Figure 26: Sankey-diagram scenario 2 Bhopal



7.1.4 Haridwar

The status quo scenario is based on the data and information gathered in 2017. The most relevant aspects are (see also underlined passages in chapter 5.3.3):

- Waste generated: 237 TPD (includes estimated waste generation due to religious festivities)
- 67 TPD non-collected waste, 100% scattered
- 170 TPD collected waste (collection rate 72%), thereof 110 TPD source segregated and 60 TPD unsegregated
- 100% disposal at unsanitary landfill site
- informal recycling activities like the observed segregation of recyclables from the landfill site are not included as not within scope
- For MSW disposed of at Sarai dumpsite 10% landfill fires are assumed

The Sankey-diagram for the status quo scenario is shown in Figure 27. The scattering of the non-collected waste does not cause methane emissions due to aerobic conditions. However, this practice should be avoided by all means as scattered waste may cause severe hazards to human health and the environment. Especially in Haridwar scattering is a severe problem due to waste disposed of into the Ganga river which not only contaminates the water but also adds to plastic waste in the ocean.

The Sankey-diagrams for the optimization scenarios are presented in Figure 28 and Figure 29. In both scenarios it is assumed that 45% source segregation of wet/organic waste can be realized. In scenario 1 the share of source segregated recyclables is assumed to be 10% which leaves 45% remaining wet/mixed waste for mechanical-biological treatment. The figures for scenario 1 and 2 also display the assumption that wet/source segregated organic waste and remaining wet/mixed waste can be processed in the SWM facility under construction (Figure 19) in a 2 line operation. Mixing of the two waste streams must be avoided to be able to produce high quality compost from the wet/source segregated organic waste stream.

In scenario 2 it is assumed that littering is stopped completely which means that no more waste is introduced into the open sewers and mixed with silt. The silt is still considered in the scenario although it is not part of the MSW anymore. This is a requirement of the LCA method that scenario comparison is only allowed with constant total waste amounts. Nevertheless, the inert silt material which is assumed to be disposed of does not contribute to the GHG emissions. On the other hand the exclusion of the silt material from the MSW stream allows higher recycling rates, and combined this leads to a considerably lower remaining wet/mixed waste fraction in scenario 2. The latter can be reduced to 23% of the total waste generated and the source segregated recyclables can be increased to 15%.

Although no anaerobic digestion is assumed for Haridwar as the investment for a modern low emission plant may not be feasible for small cities this may be done nevertheless for example through co-processing in anerobic digestion plants which process e.g. energy crops and/or agricultural waste. However, to prevent high methane emissions such a plant should be equipped with gastight storage for the digestate.

Cooperation with the agricultural sector may also be possible for co-incineration. The impurities which in the scenarios for Haridwar are supposed to be disposed of could alternatively be co-incinerated e.g. in WtE plants processing agricultural residues. Although, this is not considered in the scenarios because the scope is restricted to MSW in the responsibility of municipalities, this could further elevate potential GHG mitigation. Municipalities could take this into account and try to get information about possibilities for co-processing or for cooperation.

Figure 27: Sankey-diagram status quo Haridwar

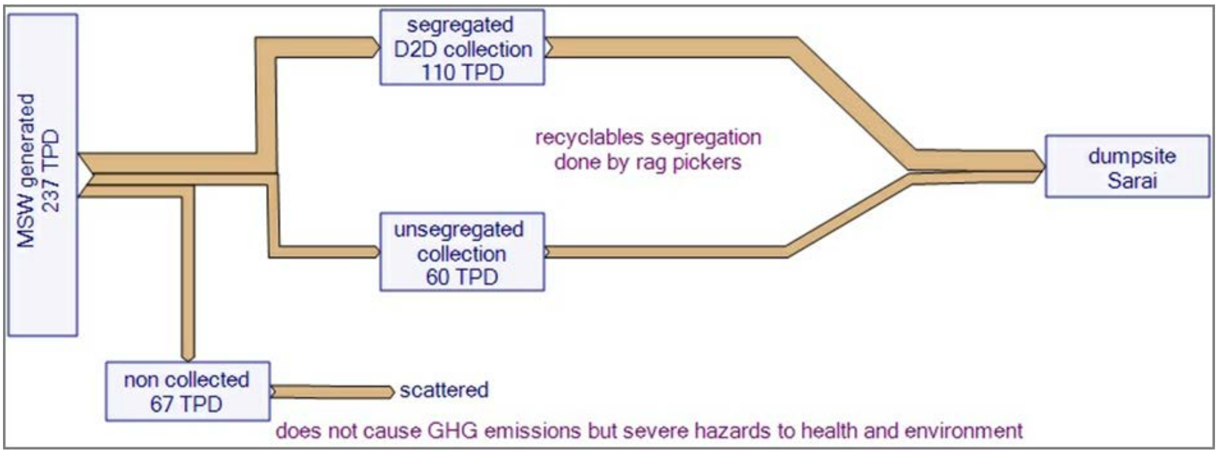


Figure 28: Sankey-diagram scenario 1 Haridwar

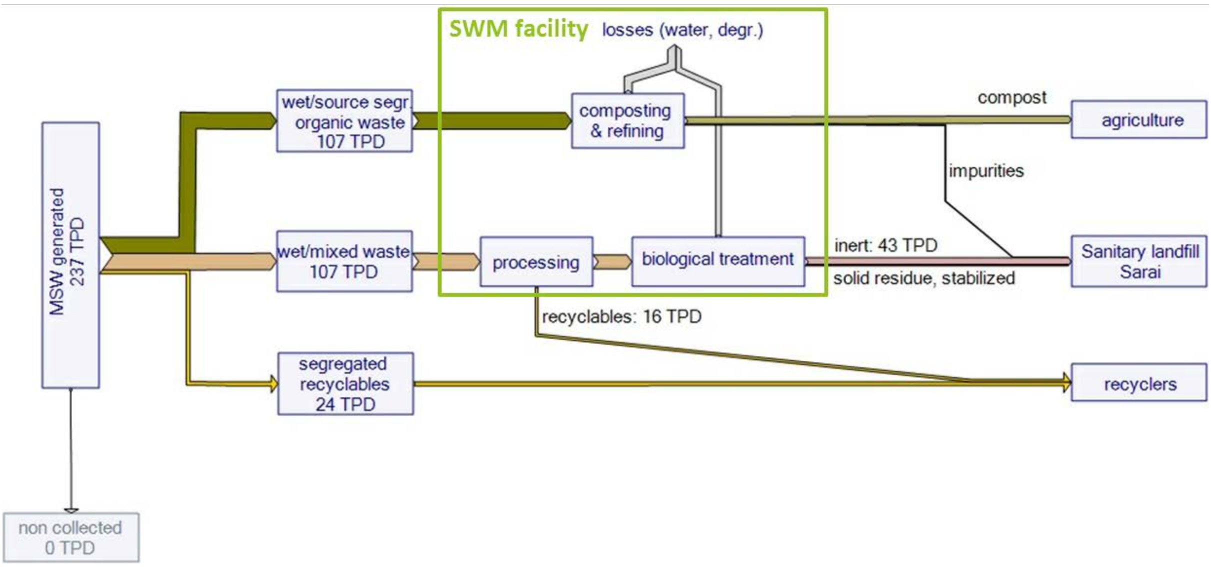
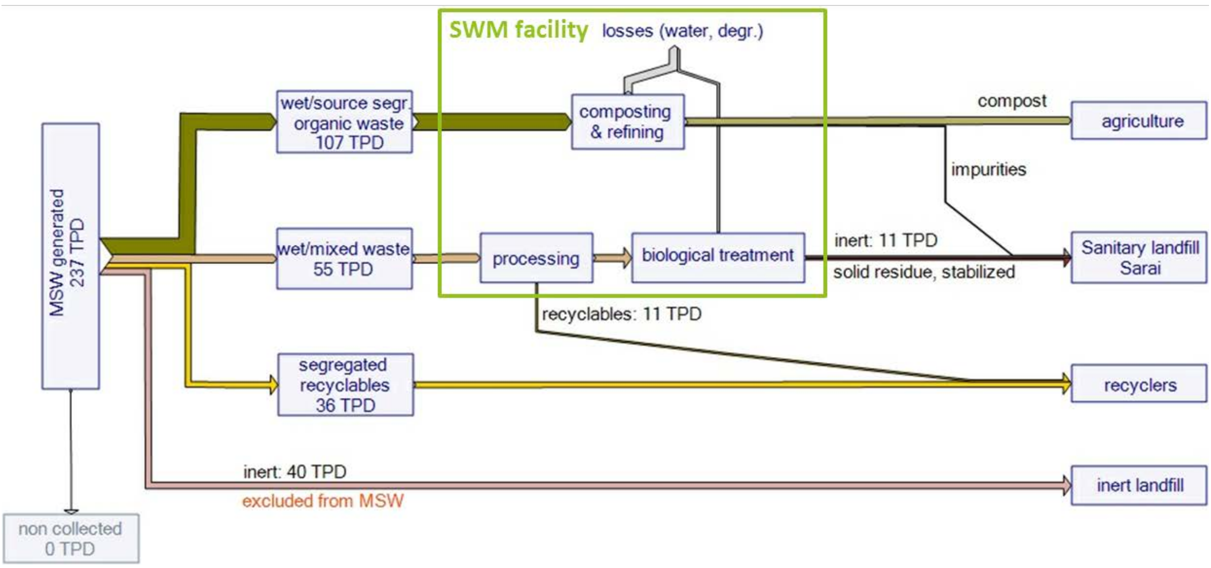


Figure 29: Sankey-diagram scenario 2 Haridwar



7.2 GHG calculation and results

General assumptions and relevant parameters for the calculation are explained in chapter 7.2.1. The GHG results are shown in the subsequent chapters in the form of two sets of diagrams: (1) in so-called sectoral bar diagrams and (2) in bar diagrams with absolute and specific net results (per ton waste and per capita).

How to read the sectoral bar diagrams:

- The results are given in CO_2-equivalents (CO_2eq) per year which represent the global warming potential of GHG emissions calculated with the most recent characterization factors from IPCC (2013) (see chapter 13.1.3);
- the results consist of a first bar with positive and negative values subdivided in sectors and of a second bar with net results (difference between positive and negative values);
- positive values reflect direct emissions from waste management like methane emissions from landfilling or fossil CO_2 emissions from incineration;
- negative values reflect potentially avoided emissions through energy generated and secondary products like compost or recycled material which have the potential to substitute primary production in other sectors than the waste sector (further explanation see chapter 13.1.1).

Both in the sectoral bar diagrams and in the diagrams with net results “accurate” figures for the net results are shown. This must not hide the fact that the GHG results are based on a series of assumption and are by no means exact. This also accounts for the sectoral results which are given in tables in the annex, chapter 13.2. The results can serve as a good orientation but as long as no reliable input data is available they cannot be accurate. This is also the reason why rounded figures are used to discuss the national potential in chapter 8, and why the influence of input data is highlighted in chapter 9.

7.2.1 Assumptions for the calculation

General assumptions and background information with regard to the LCA method and data used for the calculations are given in the annex, chapter 13.1. Aside from the mass flows and thus the fate of the waste the main influence on the results derives from the substitution processes (emissions factors for potentially avoided primary production and conventional energy generation) and the characteristics of the waste fractions like especially regenerative and fossil carbon content and heating value. Due to the lack of data these parameters were either calculated based on the waste composition or – for example in case of the RDF fractions – estimated.

The calculated carbon content and heating value for the MSW generated is given in Table 8. The respective values for the waste fractions used to calculate these parameters are shown in the annex in Table 13. From the values given in Table 8 only the regenerative carbon content is relevant for the GHG calculations with regard to methane emissions resulting from disposal of MSW generated. The figures for fossil carbon and heating value are not directly used as no incineration of MSW generated takes place.

Incineration of waste is assumed in scenarios for Bangalore and Bhopal: incineration of mean or high quality RDF derived from MBT, incineration of source segregated combustibles (Bhopal) and incineration of residual wet/mixed waste (Bangalore scenario 2b). The values for the latter are calculated from the waste composition of the residual wet/mixed waste. Otherwise the parameters fossil carbon content and heating value are estimated respecting available data. The respective parameters are comparably low in MSW generated in Bhopal (see Table 8). Therefore, it is estimated that also the fractions “RDF, mean quality” and “source segregated combustibles” are characterized by somewhat lower values than for Bangalore. For Bangalore the respective values are estimated based on the findings in (Weichgrebe et al. 2016). The values used for calculation are given in Table 10.

Table 10: Estimated values for waste incinerated

Waste fraction	Bangalore	Bhopal
RDF, high quality		
Heating value [MJ/kg]	12.5	
Fossil carbon [% mass]	12.5	
RDF, mean quality		
Heating value [MJ/kg]	11	9
Fossil carbon [% mass]	11	8
source segregated combustibles		
Heating value [MJ/kg]		9
Fossil carbon [% mass]		8
residual wet/mixed waste		
Heating value [MJ/kg]	7.4	
Fossil carbon [% mass]	6.8	

Major GHG emissions derive when organic waste is disposed of under anaerobic conditions. The methane generation from one ton of waste – over a time period of up to 100 years – depends on the content of regenerative or degradable organic carbon (DOC) and local conditions. Due to the lack of regional or national data, landfilling is basically calculated using default values of the Intergovernmental Panel on Climate Change (IPCC) which are listed in the annex, chapter 13.1.2.

In general, the defaults are used for the degradation rate (DOCf) and the methane content in landfill gas generated with the exception of stabilized solid residues which have a much lower degradation potential. For this fraction the DOCf is set to 10% and the methane content to 40 Vol%, both based on experiences and measurements in Germany. The DOC of the stabilized solid residues is assumed to be 40% of the original regenerative carbon content in the MSW generated as typically aerobic biological treatment over a time period of about 8 weeks is combined with a degradation rate of 60%. Another relevant parameter for methane emissions from landfill is the methane correction factor (MCF). This factor considers the degree of anaerobic conditions in a landfill body. 100% methane generation is assumed for managed disposal sites and only 80% for deep and 40% for shallow unmanaged sites.

In all the 3 cities disposal sites are unmanaged, and in Bhopal and Haridwar the dumpsites are shallow (not higher than 5 m). For Bangalore the situation is more complex as several disposal and dump sites are relevant. Principally, the MCF of 0.4 used in India's second communication to the UNFCCC (MoEF 2012) could be used for the calculations. Nevertheless, experts from the workshop in Bangalore stated that 2 of the disposal sites are higher than 15 m. In the light of these uncertainties, the MCF for uncategorized disposal sites of 0.6 is used for Bangalore.

All these assumptions are very relevant for the GHG results. The influence of different parameters for different treatment options is illustrated in chapter 9 to highlight that waste data matters.

7.2.2 Bangalore

The GHG results for Bangalore shown in Figure 30 and Figure 31 reveal very clearly a high GHG mitigation potential with all optimization scenarios. The major reason for the mitigation effect is diversion from landfill. Where in the status quo scenario methane emissions from disposal of non-collected, non-processed and dumped waste as well as disposal of low quality RDF from MBT effectuate the net debit results these emissions are avoided in the optimization scenarios. The GHG net results are reversed from a net debit of about 500,000 ton CO_2eq per year in the status quo scenario to a net credit of about -300,000 ton CO_2eq per year in scenario 1 up to about -370,000 ton CO_2eq per year in scenario 2.

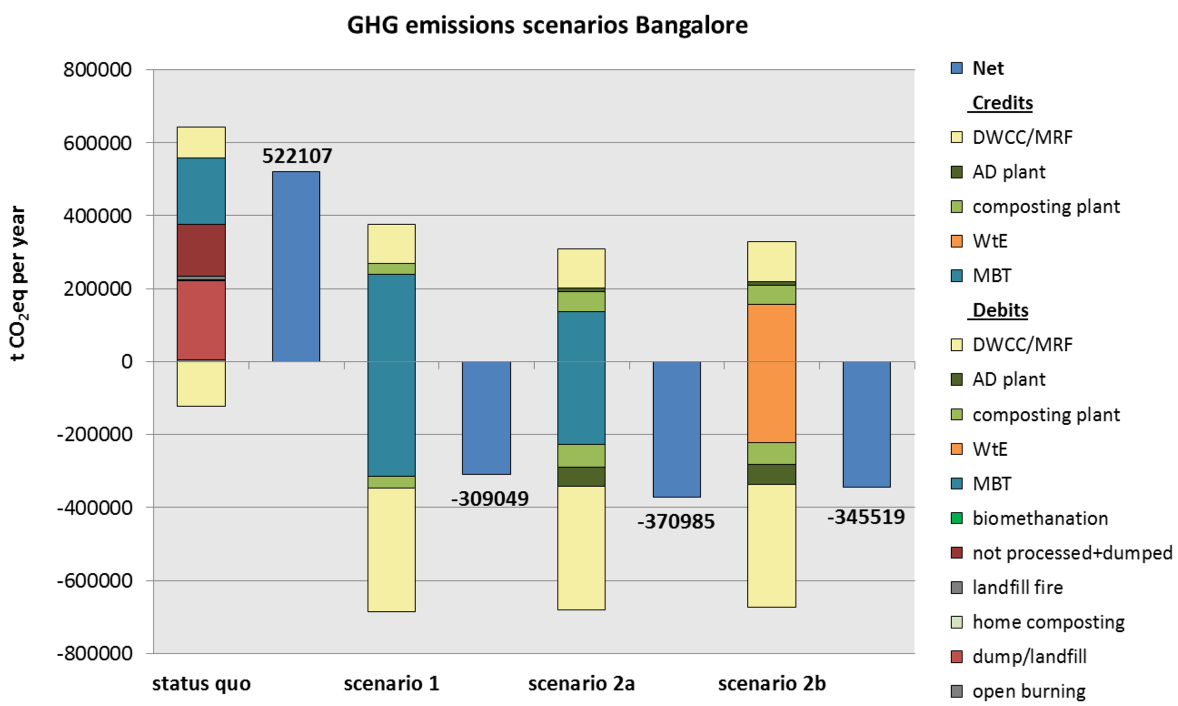
Further direct GHG emissions result from the biological treatment of wet/mixed waste in the MBT which also accounts for scenario 1 and scenario 2a, though in the latter to a less extent as less waste is treated via MBT.

Both, direct and avoided GHG emissions result from recycling which takes place in Bangalore to some extent under the responsibility of the municipality ("DWCC/MRF"). These emissions are calculated based on harmonized emission factors and include not only sorting in the DWCC but also further processing steps like e.g. melting of metals. Generally, the avoided emissions from recycling exceed the direct emissions. Especially recycling of paper, metals and textiles contribute to GHG savings which explains the increase of net credits for recycling in the optimization scenarios. The contribution from recycling to GHG mitigation would presumably be much further enhanced if informal recycling is included.

Composting of the wet/source segregated organic waste shows only small contributions to the results. Both direct and avoided emissions are in the same range. This must not be misunderstood that composting is not important for climate protection. Although, the net result for composting itself is near zero, composting of organic waste enables diversion from landfill and thus is the major driver for the prevention of methane emissions from landfilling. As an alternative this could also be achieved with anaerobic digestion. But this requires treatment in efficient low emission plants. The results in Figure 30 ("AD plant") correspond to such a plant, and only than avoided emissions are considerably higher than direct emissions.

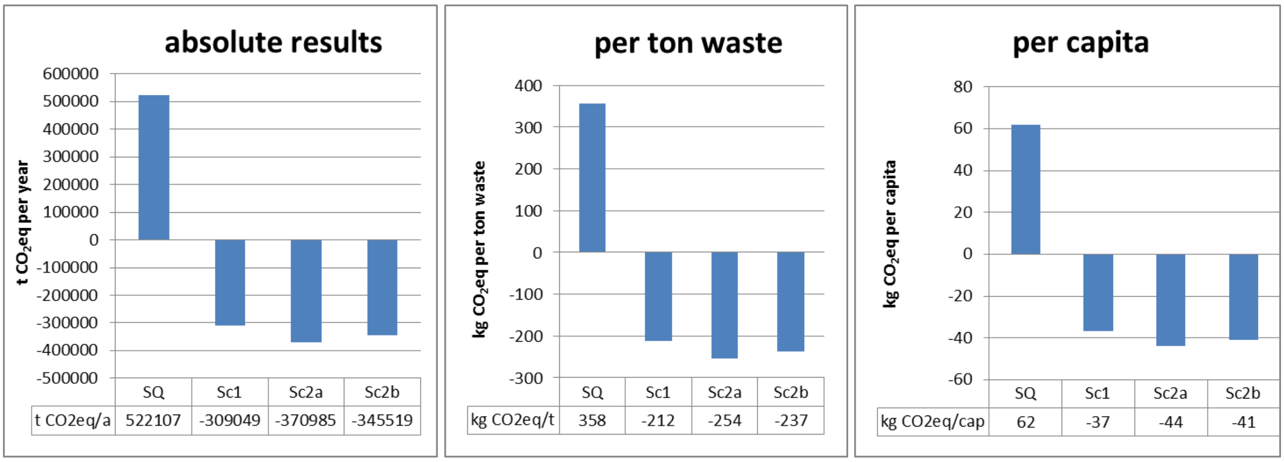
The results for scenario 2a and scenario 2b are very similar. From a climate change point of view it does not matter much if the remaining wet/mixed waste is treated in a MBT producing RDF for co-incineration or if it is incinerated directly in a WtE plant. Nevertheless, in both cases the relevant parameters heating value and fossil carbon content are based on assumptions. In practice sampling tests would be mandatory before decisions can be made.

Figure 30: Sector specific GHG results status quo and optimization scenarios Bangalore



The specific per capita net results in Figure 31 of the status quo scenario and of scenario 2a are used for the extrapolation of the GHG results for city clusters in chapter 8.

Figure 31: GHG net results in absolute terms, per ton waste and per capita – Bangalore



7.2.3 Bhopal

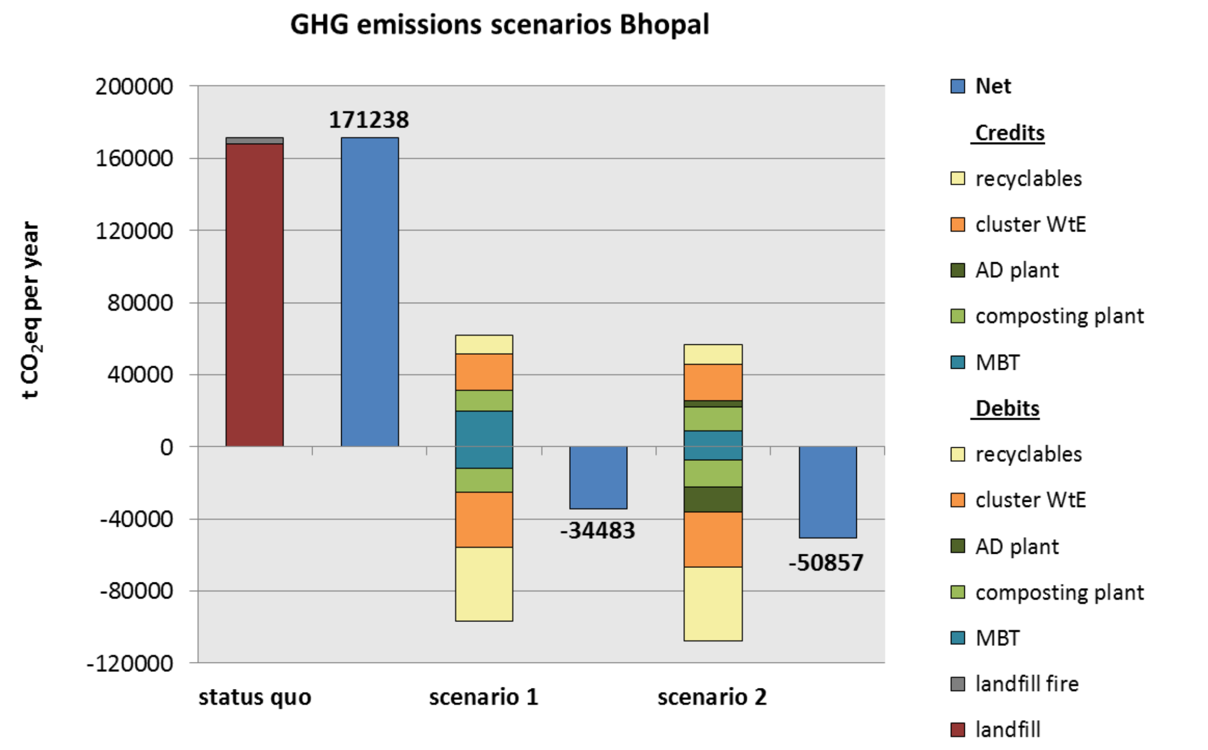
The GHG results for Bhopal shown in Figure 32 and Figure 33 reveal the same effect as explained for Bangalore. Through diversion from landfill a considerable GHG mitigation is achieved with the optimization scenarios. The GHG net results are reversed from a net debit of about 170,000 ton CO_2eq per year in the status quo scenario to a net credit of about -34,000 ton CO_2eq per year in scenario 1 and about -51,000 ton CO_2eq per year in scenario 2.

The status quo scenario for Bhopal is determined by methane emissions from the disposal of collected MSW, a small debit also derives from fossil CO_2 emissions from landfill fires. Both are completely avoided in the optimization scenarios. In contrast to Bangalore, for Bhopal no credits are achieved in the status quo scenario as all MSW under the responsibility of the municipality is landfilled. This would be much different if also informal recycling activities would be included.

Also in contrast to Bangalore, the treatment of wet/mixed waste via MBT leads to net debits. Both in scenario 1 and 2 the direct emissions are higher than the avoided emissions, although the difference is lower in scenario 2. This is due to the fact that the waste composition for Bhopal is characterized by a higher share of organics which results in higher absolute GHG emissions from the biological treatment that cannot be compensated by the produced and co-incinerated mean quality RDF fraction. The GHG emissions from the co-incineration of the RDF fraction itself are similar to the treatment of source segregated combustibles which shows a net credit ("cluster WtE", direct emissions lower than avoided emissions).

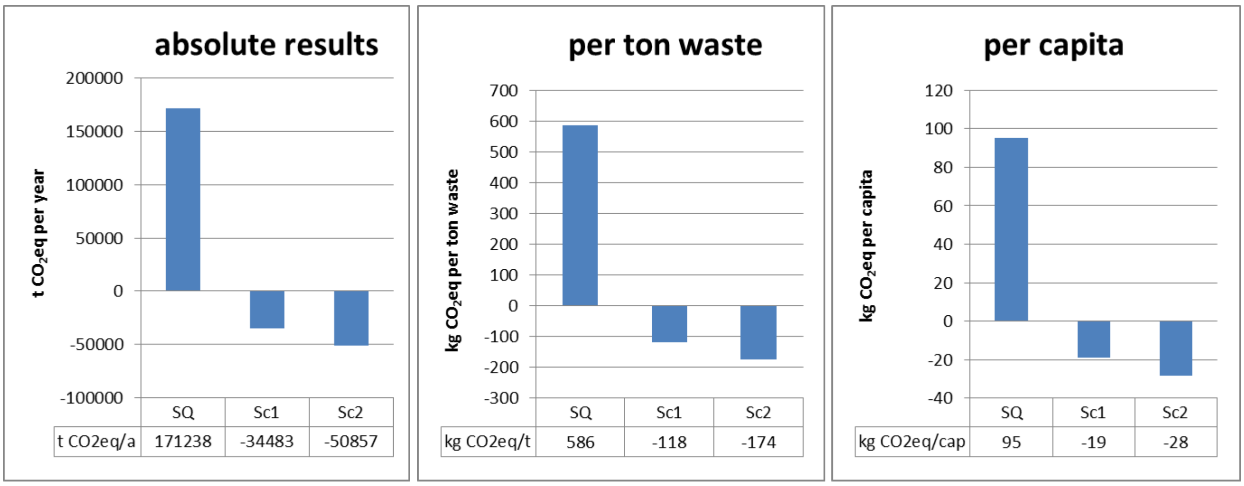
The GHG mitigation effect from recycling in the optimization scenarios is similar to that explained for Bangalore. The higher total net credit in scenario 2 compared to scenario 1 is explained by the increase of source segregated wet/organic waste which is partly treated in an efficient, low emission AD plant.

Figure 32: Sector specific GHG results status quo and optimization scenarios Bhopal



The specific per capita net results in Figure 33 of the status quo scenario and of scenario 2 are used for the extrapolation of the GHG results for city clusters in chapter 8. Compared to the specific results for Bangalore those for Bhopal are combined with higher specific net debits in the status quo scenario and lower specific net credits in the optimization scenarios. This can be explained by the different waste composition. Bangalore has more recyclables in its waste and considerably less organic material (see Table 8). Thus the waste properties are different. The major GHG mitigation effect from organic waste comes from diversion from landfill and not so much from the treatment of that material (save AD plant). This is the reason why the difference between the specific results of the status quo scenario and the scenario 2 are higher for Bhopal (-124 kg CO_2eq/cap) than for Bangalore (-106 kg CO_2eq/cap). The specific GHG mitigation is higher for cities which so far basically dispose of MSW.

Figure 33: GHG net results in absolute terms, per ton waste and per capita – Bhopal



	SQ	Sc1	Sc2
t CO2eq/a	171238	-34483	-50857

	SQ	Sc1	Sc2
kg CO2eq/t	586	-118	-174

	SQ	Sc1	Sc2
kg CO2eq/cap	95	-19	-28

7.2.4 Haridwar

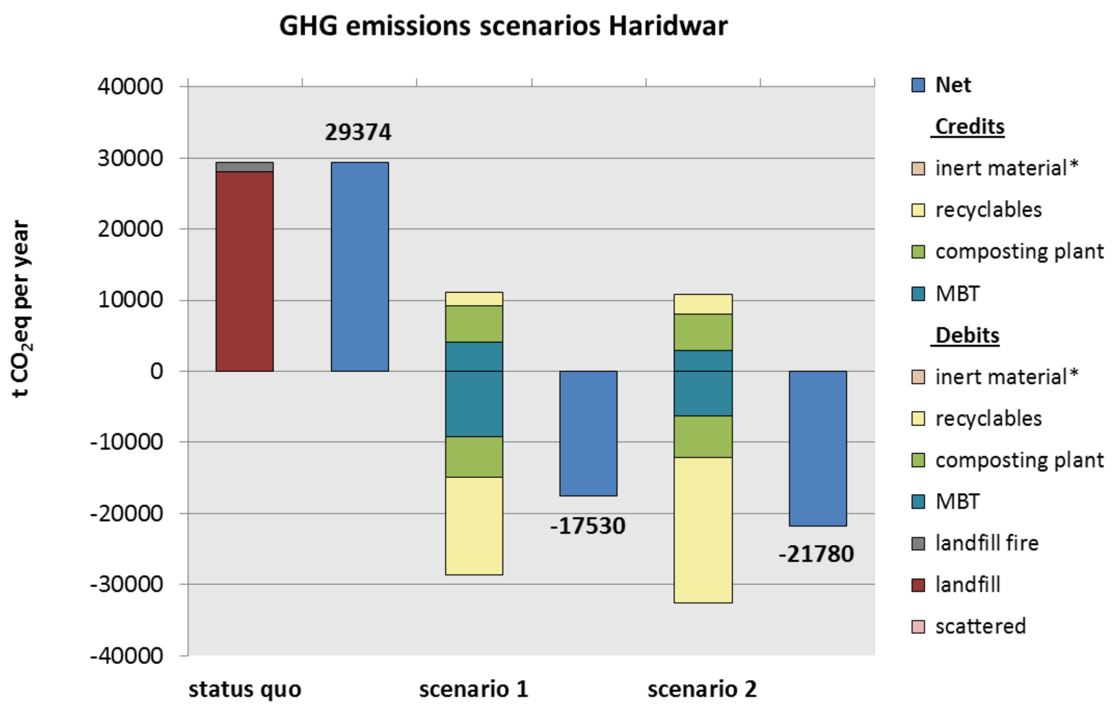
The GHG results for Haridwar shown in Figure 34 and Figure 35 again show the same effect as for Bangalore and Bhopal. Diversion from landfill leads to a considerable GHG mitigation in the optimization scenarios. The GHG net results are reversed from a net debit of about 29,000 ton CO_2eq per year in the status quo scenario to a net credit of about -18,000 ton CO_2eq per year in scenario 1 and about -22,000 ton CO_2eq per year in scenario 2.

Like for Bhopal the status quo scenario for Haridwar is determined by methane emissions from the disposal of collected MSW and a small debit from fossil CO_2 emissions from landfill fires which are both completely avoided in the optimization scenarios through diversion from landfill. In contrast to Bhopal the status quo scenario for Haridwar includes scattered waste which does not contribute to climate change due to aerobic conditions. Nevertheless, this practice shall be avoided as it may cause severe hazards to human health and the environment and adds to marine littering.

Also in contrast to Bhopal but like in Bangalore the mechanical-biological treatment of wet/mixed waste in the optimization scenarios leads to net credits due to the different proportions of organic and recyclable waste in the waste composition. The results for composting and recycling in the optimization scenarios are similar to those for Bangalore and Bhopal.

The difference between scenario 1 and scenario 2 derives from the exclusion of silt from MSW. The silt is considered inert and not combined with methane emissions from disposal while on the other hand the quality of source segregated recyclables is enhanced which results in higher absolute net credits for recycling.

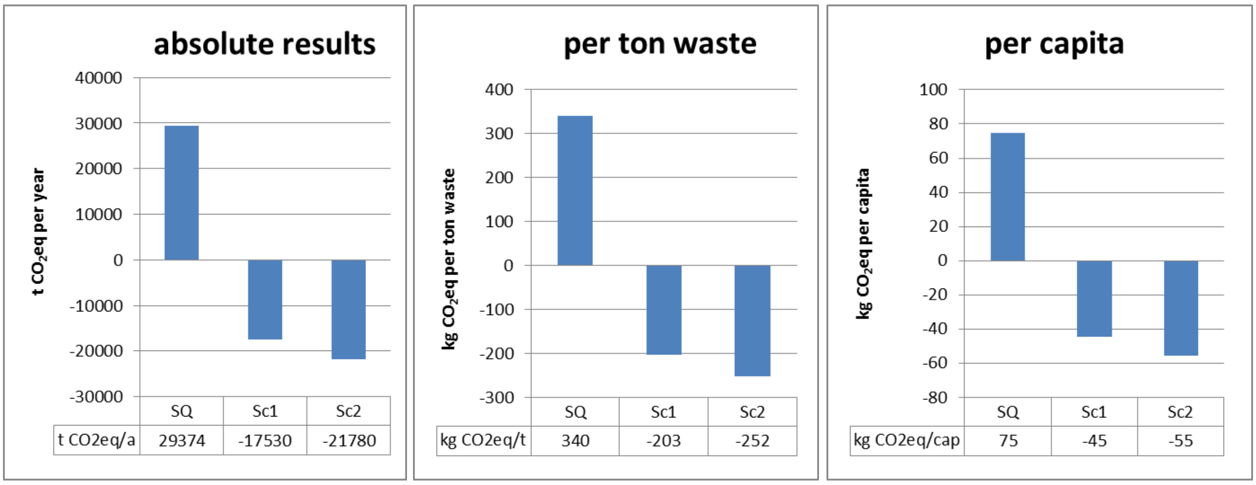
Figure 34: Sector specific GHG results status quo and optimization scenarios Haridwar



* silt excluded from MSW in scenario 2, inert material does not cause GHG emissions from disposal

The specific per capita net results in Figure 35 of the status quo scenario and of scenario 2 are used for the extrapolation of the GHG results for city clusters in chapter 8. The specific results for Haridwar are between those for Bangalore and for Bhopal in the status quo scenario. In the optimization scenarios this also accounts for the specific results per ton waste though the values are nearby those for Bangalore. In contrast the specific per capita results are the highest for Haridwar in the optimization scenarios. This may be due to the fact that the floating population is underestimated as also the per capita waste generation is highest for Haridwar (0.6 kg per capita and day compared to about 0.44 for Bhopal and 0.47 for Bangalore). Nevertheless, from the waste composition Haridwar has a similar share of organic waste as Bangalore although less recyclables (see Table 8). The specialty of a comparably high share of inert material is somewhat modified with scenario 2 where this fraction – which is assumed to be 17% - is excluded from MSW. The difference between the specific per capita results of the status quo scenario and the scenario 2 are highest for Haridwar (-130 kg CO_2eq/cap). However, it must not be forgotten that all results are based on assumptions and are not accurate.

Figure 35: GHG net results in absolute terms, per ton waste and per capita – Haridwar



7.2.5 Summary results

In summary, the GHG results clearly demonstrate the significant GHG mitigation potential which derives from diversion from landfill. Here, the regulatory and policy requirements in India already provide a most relevant co-benefit for climate protection. In addition, the GHG mitigation effect would be even higher if informal recycling is included.

Although, the way to an integrated waste management system is still to go, the scenario 1 for the 3 cities could be achieved as a first step within a decent time frame. Key to this is proper source segregation which needs to be improved especially in Bangalore and started in Bhopal. Pure waste fractions collected from source allow high recycling rates and the production of quality compost. Realization is surely easier in small cities as less anonymous but also possible in large/mega cities at least at less densely built-up areas. Source segregation does not need high investments into equipment, but sufficient containers and suitable transport facilities. The main investment must be on personal and on educational training for citizens and also for waste collectors.

The next important thing is proper treatment of the segregated waste. This can be done in Haridwar as proposed in the SWM facility under construction in a 2 line operation, strictly preventing the mixing of the two waste streams. In Bangalore this may be realized with the existing MBT plants. Some of them may be rededicated to process wet/source segregated organic waste only. This was done in the past in the KCDC plant and could be done again in some plants while the rest continue processing the remaining wet/mixed waste. For Bhopal new plants are needed.

The scenario 2 for the 3 cities are more challenging to realize as they consider a further increase of wet/source segregated organic waste for Bhopal and Bangalore, and for Haridwar the strict prevention of littering. Additionally, efficient low emission AD plants are assumed which need not only proper input material but also higher investments. The latter are not likely to be covered by selling biogas and compost. Such a concept needs other financing sources like e.g. waste service fees.

Nevertheless, both scenarios 1 and 2 are feasible. Both already provide a significant GHG mitigation although they are not ideal scenarios. The dimension of the achievable GHG mitigation through diversion from landfill is rather robust even though the scenarios are basically based on assumptions.

Prerequisite to implement functional waste management systems is to know the waste properties as they decide on possible treatment routes, and to know the waste quantities as they decide on the necessary capacities. This requires to undertake representative MSW analysis, e.g. as proposed in the "MSWM Manual 2016" (see chapter 4.2). In addition, MSW from bulk generators should be taken into account as this waste ends up in the municipal waste stream all the same. In addition, pilot tests should be done prior to decide on investments in treatment plants.

The waste properties also determine the GHG results. For example for Bhopal the results reflect the high share of organics in the waste composition which leads to net debits for the remaining wet/mixed waste treated in MBT. If the assumptions on the waste composition are accurate then Bhopal should put in great efforts on source segregation of wet/organic waste and composting. Although composting also generates methane and di-nitrous oxide emissions, these emissions can be minimized by good professional operation which does not need enclosed high-tech plants but could be done in several medium sized open plants. Most relevant is to respect a proper surface-volume-relation like in triangular windrows, the right carbon-nitrogen content, sufficient aeration, and sufficient water. Another example is the approach of different concepts for Bangalore in scenario 2a and 2b. If the assumptions on the waste characteristics are true then from a climate protection point of view it does not matter which of the two concepts a city opts for.

In general, municipalities should also look for possible cooperation with other cities to realize e.g. a cluster WtE concept or for possible cooperation with other sectors like co-incineration in cement kilns or maybe also co-incineration in WtE plants using agricultural residues. However, co-processing of MSW in other sectors always needs to examine first if this is compliant with environmental needs.

8 Extrapolation of GHG results for city clusters

The one of the reasons to cover 3 different city sizes in this research was to respect the broad differences in India which are combined with different framework conditions for waste management. Another reason is to analyze the potential GHG mitigation effect which improvements in waste management by mega/large cities, medium sized cities and small cities may contribute to the total national mitigation potential of the waste sector and in this way support decision-making on a broader scale.

The 3 defined city clusters are:

- large/mega cities: 3-8 million inhabitants represented by Bangalore
- medium cities: 1-3 million inhabitants represented by Bhopal
- smaller cities: 0.1-1 million inhabitants represented by Haridwar

According to Michaelowa et al. (2015), citing CPCB, especially large cities or states with a high level of urbanization generate relevant shares of the total waste generation in India. For example Maharashtra, Uttar Pradesh, Tamil Nadu and Andhra Pradesh – the states with high levels of urbanization – together generate over 50% of the total MSW generation in the country. And at city level, there are 53 cities above 1 million inhabitants (including outgrowth) that generate more than 40% of the total waste generated in India in 2011. In addition, due to a further increase of urbanization through population growth and migration into cities it is expected that this effect will become even more important in the future.

This explains why usually the main focus of decision-makers regarding improvements in waste management and GHG mitigation as a co-benefit is on large/mega cities and/or cities above 1 million inhabitants. Smaller cities rarely benefit from subsidies and promotional programs. One of these exceptions is Haridwar due to its religious and spiritual importance (see chapter 4.3).

Being a pilgrimage destination at Ganga river makes Haridwar's waste sector special in two ways: (1) waste is not only generated by the inhabitants but also by the floating population which is estimated to be 165,000 people per day on average (CPCB 2016); (2) the waste composition has a comparatively high share of inert material (24%) which is assumed to result from removing waste and associated silt from Haridwar's open sewer system. In addition, Haridwar is a strict vegetarian city. Therefore, Haridwar might not be typical for the city cluster of 0.1 to 1 million inhabitants. However, open sewer systems are rather frequent also in other cities, and the population share of vegetarians in India of about 40% is the highest worldwide. Ultimately, Haridwar can be used as a proxy having in mind that the extrapolation of GHG results for the three city clusters is not meant to be exact, and cannot be exact due to the existing data gaps and in consequence necessary assumptions.

For extrapolation purposes the population data of the census of India 2011 were used. According to (ORGI 2018a) India's total population size was 1,210,569,573 in 2011, with an urban population of 377,106,125 (31%). Information on cities[12] was derived from ORGI (2018b), Table A-4 'Towns And Urban Agglomerations Classified By Population Size Class'. Class-I (100,000 and above) includes 298 urban agglomerations and 170 towns with a population of 264,745,519 in 2011 (70% of total urban population). Analyzed data for the three city clusters are presented in Table 12. For the extrapolation the population of the towns is used as also the data on the 3 cities, Bangalore, Bhopal and Haridwar refer to the town level and not the urban agglomeration[13]. The population of the 424 smaller towns

[12] "Towns with population of 100,000 and above" (ORGI 2018c).

[13] "A continuous urban spread constituting a town and its adjoining outgrowth (OGs), or two or more physically contiguous

(0.1-1 million) cannot easily be accessed and is estimated to be 80% of the population of towns and urban agglomerations as the difference decreases with city size (see Table 12).

The GHG results used for extrapolation are presented in Table 11. The GHG mitigation potential is derived from the results for the status quo scenario and scenario 2 of the 3 cities. The per capita results for Haridwar are referred to the population including the floating population which adds up to approximately 394,000 people, and calculates to a per capita waste generation of 0.6 kg/cap/day for Haridwar. In comparison the per capita waste generation for Bhopal is 0.44 and for Bangalore 0.47 kg/cap/day respectively. The higher figure for Haridwar is partly plausible as smaller cities usually have a lower population density where typically more waste is generated per capita, but partly may also be due to the special situation of the pilgrimage city. Bhopal and Haridwar show a higher per capita mitigation potential than Bangalore. This is mainly due to the fact that the 2 cities are basically dumping their waste in the status quo while in Bangalore MSW is already partly treated.

Table 11: Population and GHG results of selected cities

City		Bangalore	Bhopal	Haridwar
Population as per census 2011 + floating population Haridwar	town	8,425,970	1,798,218	228,832 +165,000
Waste generated	t/a	1,460,000	292,000	86,505
Status quo GHG net results per capita	kg CO_2eq/cap	62	95	75
Scenario 2(a) GHG net results per capita	kg CO_2eq/cap	-44	-28	-55
GHG mitigation potential per capita	kg CO_2eq/cap	-106	-124	-130

Sources: (ORGI 2015), calculations ifeu

Table 12: GHG mitigation potential city clusters, Class-I (100,000 and above)

Inhabitants, cluster	total	above 3 million	1-3 million	0,1-1 million
number of towns & urban agglomerations	468	10	34	424
population towns & urban agglomerations	264,745,519	92,706,519	66,874,696	105,164,304
population towns[1]		61,100,000	49,400,000	84,100,000[2]
share in %		66%	74%	80%[2]
GHG mitigation potential[1] [t CO_2eq/a]	-23,500,000	-6,500,000	-6,100,000	-10,900,000
share in %		28%	26%	47%

1. Rounded values are used to avoid the impression of exactness.

towns" (ORGI 2018c).

2. conservative estimated for share of population in municipal corporations in smaller cities
Sources: (ORGI 2018c), calculations ifeu

The results in Table 12 show that the extrapolated GHG mitigation potential of the 3 city clusters is nearly equal for the 10 larger towns and the 34 medium sized towns. Both contribute to approximately one quarter to the total extrapolated mitigation potential. The 424 smaller towns contribute to 47% to the extrapolated GHG mitigation potential. Even if this contribution is overestimated due to the special situation for Haridwar, the results illustrate that the sum of smaller towns are a relevant factor for GHG mitigation through waste management.

9 Waste data matters – reliability of GHG results

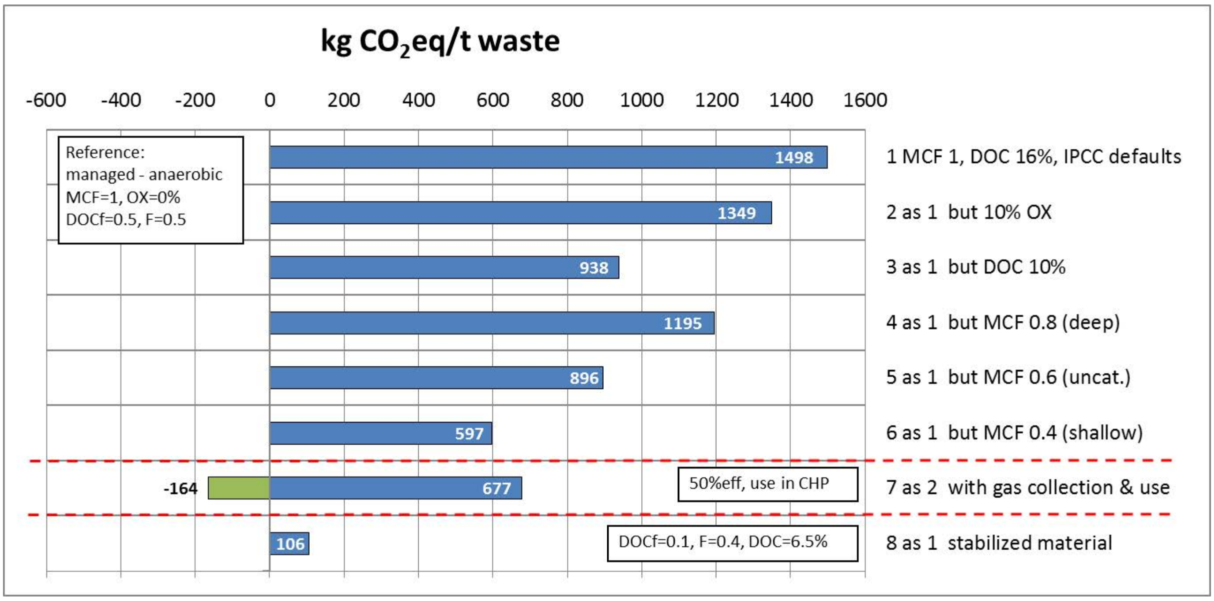
The GHG results calculated for the 3 cities had to be based on assumptions. Although, the order of magnitude for the GHG mitigation through diversion from landfill is robust, the GHG results are considered too inaccurate and nonbinding to be accepted for example by financing institutions like e.g. the NAMA facility or for NDCs (see chapter 10). Already for the status quo scenario the possible variations in dependence of input data are high. This is demonstrated in the following with specific GHG results for the most relevant treatment options:

1. Solid waste disposal
2. Incineration
3. Composting & anaerobic digestion for wet/source segregated organic waste
4. Mechanical-biological treatment of wet/mixed waste
5. Plastics recycling due to quality

The figures presented show direct emissions (positive values in bars to the right) and avoided emissions (negative values in bars to the left).

1. Main GHG emissions from **solid waste disposal** are methane emissions derived from anaerobic degradation of organic material like green/garden waste, food/kitchen waste, paper and cardboard, wood, and textiles, rubber, leather, nappies of biogenic origin (e.g. cotton or gained from animals). The degree of methane generation mainly depends on the regenerative or degradable organic carbon (DOC) content, the degradation rate (DOCf) which depends on the kind of organic compounds (carbohydrates, proteins, fat, hemicellulose, cellulose, lignin), the degree of anaerobic conditions in the disposal site (considered by the methane correction factor). Furthermore, the finally emitted methane depends on a gas collection system, landfill gas treatment and management practice regarding possible oxidation of methane.

Figure 36: Variations solid waste disposal



To support countries which have no national data the Intergovernmental Panel on Climate Change provided guidelines for National Greenhouse Gas Inventories including default values (IPCC 2006). However, already the choice of these default values can change results considerably. In Figure 36 specific results for the most relevant variations of disposal are presented. In case 1, the reference, the default values for a managed - anaerobic disposal site are used with 100% methane generation (MCF=1), no oxida-tion (OX=0%), DOCf=0.5 and a methane content (F) of 0.5. The DOC is set to 16% which is nearby the value for Bangalore (see Table 8). In variation case 2 shows the result for a well-managed landfill with oxidation layer (OX=10%). Case 3 is identical to case 1 but with a lower DOC of 10%. The cases 4 to 6 show variations of case 1 for different anaerobic conditions, with case 4 a deep disposal site with 80% methane generation, case 6 a shallow disposal site (< 5 m) with 40% methane generation, and case 5 the average of 60% methane generation for uncategorized disposal sites. Already these examples demonstrate the high variation of the specific results which would multiply with the total waste amount deposited. Especially if the DOC and the conditions of the disposal site (MCF) are not known or wrongly estimated the specific results vary up to factor 3.

Case 7 represents the well-managed disposal site of case 2 with a gas collection system installed. A maximum collection efficiency over the 100 time period of 50% is calculated and use of the landfill gas in a CHP. Generated heat and electricity are credited (net electrical efficiency 37.5% and net heat efficiency 43%). The results show that still relevant GHG emissions occur.

Case 8 represents the disposal of stabilized solid residue derived from MBT. In this case the DOC is estimated to 40% of the original DOC (6.4% of 16%; proper composting over a time period of about 2 months usually leads to 60% degradation of organics) and the DOCf is much lower (10%) and also the methane content is lower (40%). Both figures are based on experiences and measurements in Germany. Although, even in this case some methane emissions remain, they are much lower than from disposal of untreated organic waste which is the reason why this practice was chosen for scenario 1 as a first easy to achieve GHG mitigation option. However, better options for GHG mitigation are to increase source segregation and recycling. On the contrary "shallow dumping" would be like "scattering" and must not be an option for GHG mitigation. It would cost more need for space and negative impacts on human health and the environment would continue.

2. Main direct GHG emissions from **incineration** are fossil CO_2 emissions derived from oxidation of fossil carbon. Thus the fossil carbon content in the waste is a most relevant parameter. Another most

relevant aspect is energy generation. This determines the potential to avoid emissions through substitution of conventionally generated energy. The crucial parameters are heating value, energy efficiency and the potentially substituted primary process.

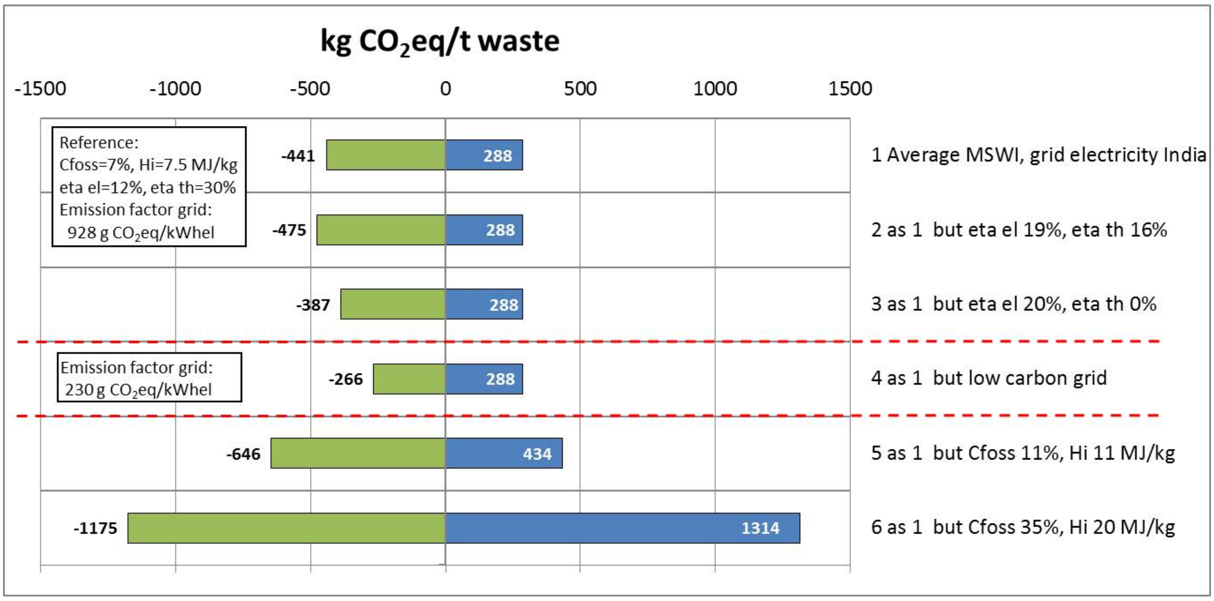
In Figure 37 specific results for the most relevant variations are presented. Case 1, the reference, represents a MSW incineration (MSWI) plant with the average energy efficiency of such plants in Germany/Europe, with an electrical net efficiency of 12% and a thermal efficiency of 30%. The fossil carbon content of the waste incinerated is set to 7% by mass and the heating value to 7.5 MJ/kg (1791 kcal/kg) which both are nearby the values for Bangalore (see Table 8). Substitution process is the conventional energy generation for India with an emission factor for electricity generation of 928 g CO_2eq/kWh, and an emission factor for heat generation of 334 g CO_2eq/kWh.

In the cases 2 to 4 the waste considered is the same as in case 1 (direct emissions unchanged) but the efficiencies and the substitution process are changed. Case 2 shows a variation with an electrical net efficiency of 19% and a thermal efficiency of 16%, and case 3 a variation with an electrical net efficiency of 20% and a thermal efficiency of 0%[14]. These variations demonstrate that combined heat and power generation are usually to prefer from a climate protection point of view, though exact proportions depend on the substituted electricity and heat. Case 4 shows a variation in case of a low carbon grid like which means conventional electricity is to higher extent generated from non-fossil fuels like for example in Canada with an emission factor for electricity generation of 230 g CO_2eq/kWh. In this case the avoided emissions are much lower and thus also the GHG mitigation effect from WtE options.

Case 5 and 6 show variations of waste properties. In case 5 the fossil carbon content is set to 11% by mass and the heating value to 11 MJ/kg (2627 kcal/kg) which corresponds to the assumption for mean quality RDF produced from MBT for Bangalore (see Table 10). In countries with a high carbon grid like India (high share of electricity generated from coal) this leads to a higher GHG mitigation as the avoided emissions prevail the direct emissions (net result in case 5 is -212 kg CO_2eq/t waste compared to
-153 in case 1). In case 6 the fossil carbon content is set to 35% by mass and the heating value to 20 MJ/kg (4777 kcal/kg). These properties are typical for mixed plastic waste, and in this case the proportion between fossil carbon content and heating value is disadvantageous and the direct emissions prevail the avoided emissions (net result +139 kg CO_2eq/t waste).

[14] An incineration plant produces electricity with a steam turbine. If only electricity is produced the maximum electrical efficiency is usually about 20% due to thermodynamic reasons (somewhat higher degrees are possible with extra technical equipment like re/over-heater). The higher the electrical efficiency the lower is the remaining potential to also produce heat. The degree of heat production usually depends on the possibility to sell the heat.

Figure 37: Variations incineration



The results demonstrate that it is very important to know the waste which is meant to be incinerated. Especially in case of (fossil) plastic waste incineration may lead to an impact on the climate. In addition, the energy system is of importance. If already a low carbon grid is installed it might be better to generate more heat depending on the conventional fuel for heat generation. In any case for waste incineration a proper flue gas cleaning is mandatory to respect human health concerns. Incineration must comply with the emission standards of the SWM Rules 2016 (see chapter 4.2).

3. The GHG emissions for **composting and anaerobic digestion for wet/source segregated organic waste** are characterized by direct methane (CH_4) and di-nitrous oxide (N_2O) emissions from the biological treatment and avoided emissions from substitution of e.g. mineral fertilizer, peat or bark humus dependent on the application. In case of anaerobic digestion additionally conventional energy generation is substituted.

Figure 38 displays 4 variations for composting and 3 for anaerobic digestion (AD). In each of these cases the substituted process is not altered but an average application of compost in agriculture, horticulture and landscaping is used, and for anaerobic digestion the same methane generation (60 m^3/t waste minus 1.5% losses) with use in a CHP with 30% net electrical efficiency and 32% net heat usage[15].

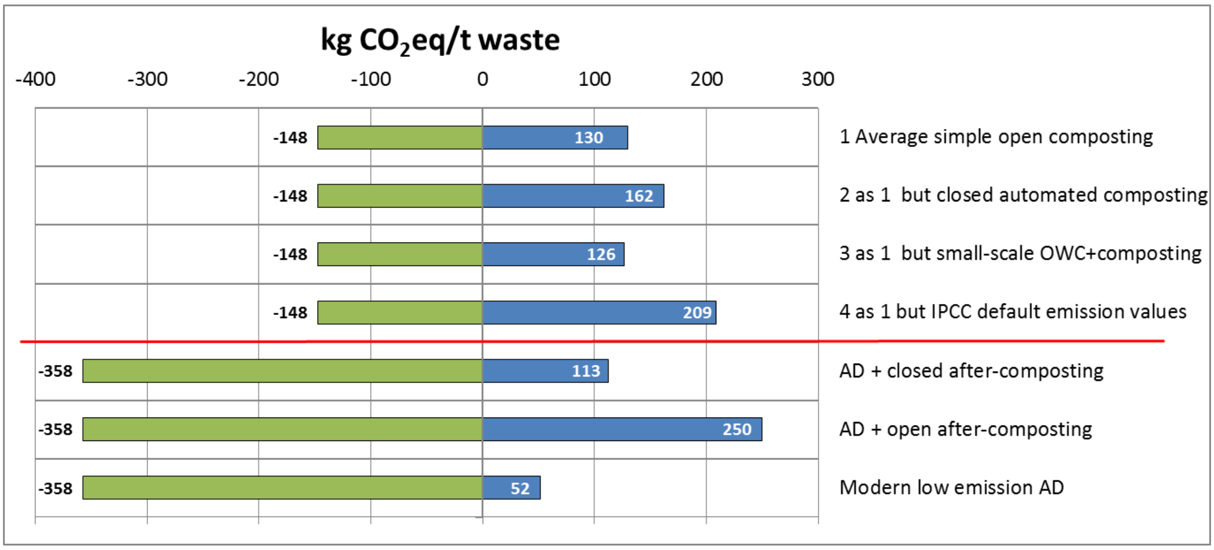
In the cases 1 to 4 the differences derive from different direct emissions (CH_4 and N_2O) and energy demand which both vary depending on the composting system. Case 1 reflects an average simple open composting, case 2 a closed automated composting, case 3 a small-scale OWC (organic waste converter) plus composting, and in case 4 IPCC's default emission factors for composting are used. The latter are the highest resulting in the highest direct GHG emissions. The emission factors used for the cases 1 to 3 are from a study for the German Environment Agency (Cuhls et al. 2015) and are based on field measurements in Germany. The same factors are used for cases 1 and 3, the factors for case 2 are slightly higher. The main difference between these 3 variations derives from the energy demand. The closed system has the highest energy demand, the OWC plus composting the lowest (value estimated).

These results illustrate the findings in Cuhls et al. (2015) that direct GHG emissions from composting

[15] "net" in this case means the energy demand of the digestion plant is substracted.

do not so much depend on high-technology-solutions but on good professional practice. Most relevant is to respect a proper surface-volume-relation like in triangular windrows, the right carbon-nitrogen content, sufficient aeration, and sufficient water. The best practice for low GHG emission composting is described in a guideline of the German association of quality compost (BGK 2010). It would be helpful to have corresponding English guidelines at hand to support operators to identify the most crucial aspects for low GHG emission operation.

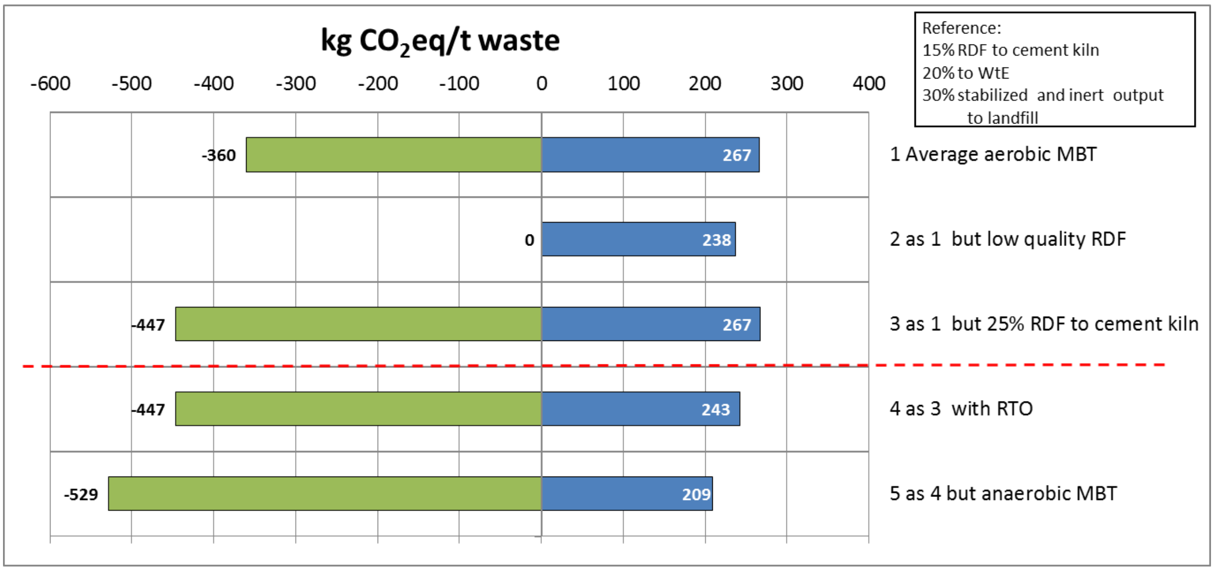
Figure 38: Variations biological treatment – composting and anaerobic digestion



The 3 variations for anaerobic digestion show a much higher influence of the after-composting dependent on the technology. Open after-composting of digestate is combined with much higher GHG emissions than closed after-composting with exhaust air collection, acid scrubber and bio filter. The emission factors are again from Cuhls et al. (2015). The depicted results of a modern low emission AD plant correspond to closed plants with gastight storage for digestate and – especially important – a so-called aerobisa-tion step where the digested residue is transformed from anaerobic conditions to aerobic conditions via enclosed aeration.

4. The GHG emissions for **mechanical-biological treatment (MBT) of wet/mixed waste** are mainly determined by the quality of operation and the quality of products. Case 1, the reference, corresponds to the MBT calculated for Bangalore in scenario 1, case 2 corresponds to the status quo scenario and case 3 to the MBT in scenario 2. In case 1, based on the given waste composition, proper separation is assumed of 15% high-quality RDF for co-incineration in a cement kiln, 20% mean quality RDF for co-incineration in a WtE plant and 30% stabilized solid residue and inert material for disposal. In case 2, like in the status quo scenario for Bangalore, no good operational practice leads to low quality RDF which has to be disposed. Therefore no credits are gained and the direct emissions from disposal are only a little lower than from incineration of the RDF fraction. In case 3, again based on the given waste composition, higher efforts for separation and refinement of the RDF fraction are assumed with 25% high-quality RDF for co-incineration in a cement kiln, 10% mean quality RDF for co-incineration in a WtE plant and again 30% stabilized solid residue and inert material for disposal. This leads to somewhat higher credits as co-incineration in a cement kiln substitutes coal by energy content which leads to higher GHG savings than the substitution of conventionally generated energy by WtE. Case 4 corresponds to case 3 with the only difference that a closed biological treatment is assumed with collection and treatment of the exhaust air via a regenerative thermal oxidation (RTO) which reduces the direct emissions from the biological treatment.

Figure 39: Variations mechanical-biological treatment plants (MBTs)

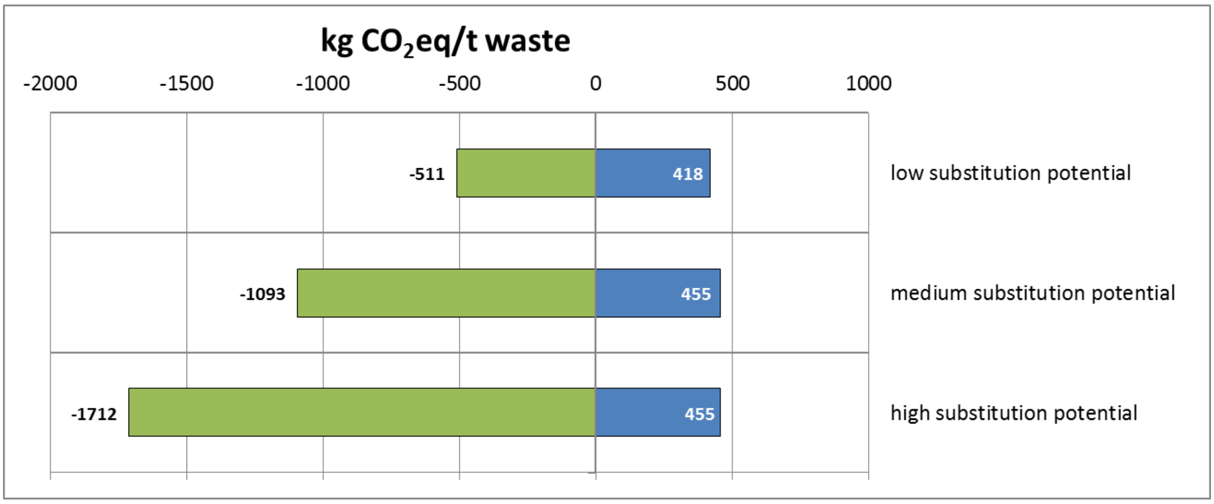


Case 5 corresponds to case 4 but an anaerobic biological treatment of the separated organic fraction is assumed. Due to biogas generation the GHG emissions from energy demand are lower (covered by biogas use), and the credits are higher due to excess energy from biogas which substitutes conventionally generated energy.

The specific GHG results shown correspond to the mass balance for Bangalore based on the given waste composition. From the results for Bhopal it was learnt that different waste compositions with a considerably higher share of organic waste will lead to net debits for the treatment of wet/mixed waste via MBT as only a smaller RDF fraction can be separated and the credit for co-incineration of this fraction cannot compensate the GHG emissions from biological treatment.

5. The GHG emissions from **plastics recycling** vary depending on the quality of the collected and processed plastic waste. Figure 40 illustrates the GHG results for recycling of low, medium and high quality plastic waste which have different substitution potentials. The low quality comes from mixed plastic waste which usually is not fit to substitute primary plastics. Secondary raw material produced is basically used for coarse, thick-walled products like palisades or benches and can only substitute primary polyethylene to some extent and otherwise wood or concrete. The medium and the high quality plastic wastes still consist of mixed plastics but also of separated pure plastics like PE and PET. The high quality plastic waste is of material which can substitute 100% primary material by mass, the me-dium quality only 70% by mass ("substitution factor").

Figure 40: Variations plastic recycling



For India the low quality plastic waste with a low substitution potential is assumed in the GHG calculations which means for plastic recycling there is still a high potential for a further increase of the GHG mitigation.

10 Context of LCA method and MRV for NAMAs or NDCs

The LCA method in waste management is a decision-making aid. The boundary conditions and methodological agreements (chapter 13.1) allow the assessment of different waste management options for a certain amount of waste. The decisive aspect is that all emissions related to the waste management activities are considered. All direct emissions from a certain amount of waste are accounted for although these emissions will happen in the future like methane emissions from landfilling, and all potentially avoided emissions are accounted for, which reflects the benefits provided by waste management like recycling or energy recovery. So the LCA method allows to model and compare impacts of different waste management decisions for a comparable amount of waste regardless when they occur.

Monitoring, reporting and verification (MRV) is typically applied to follow mitigation actions. Under the Kyoto-Protocol monitoring and reporting takes place on a yearly or biennial basis with the National Inventory Reports (NIR) of Annex I parties or the Biennial Update Reports (BURs) of non-Annex I parties[16], which are part of National Communications. MRV Systems shall comply with common international UNFCCC reporting requirements to be able to track emissions and emission reductions toward the mitigation goal (GIZ 2013). NIRs provide National GHG inventories which comply with IPCC's guidelines (IPCC 2006). The same accounts for BURs with the difference that Non-Annex I parties shall comply with the requirements to the extent its capacities permit (UNFCCC 2003). The IPCC guidelines differentiate emissions from the sectors energy, industry, agriculture, land use, land use change and forestry, and waste.

In contrast to the LCA method in waste management the waste sector in the GHG inventory focuses on non-energy emissions only, and basically includes solid waste disposal, biological treatment (composting, anaerobic digestion without biogas use), open burning and incineration without energy generation and mechanical-biological treatment. Reported emissions from solid waste disposal are emitted

[16] Annex I parties are countries which ratified the Kyoto-Protocol of 1997. The majority are industrialized countries. Non-Annex I parties refers to countries that have ratified or acceded to the UNFCCC, but are not included in Annex I of the Convention. The majority are low-income developing countries and emerging economies. Non-Annex I Parties have no binding commitments to cut their emissions under the Kyoto Protocol.

emissions in the year of reporting which derive from waste amounts disposed of in earlier years. Incineration with energy generation and biogas use are reported under the energy sector and recycling is indirectly included in the industry sector. Crediting GHG emissions potentially saved by waste management in other sectors is not an option in order to prevent double accounting.

So, comparing the LCA method and the GHG inventory reveals that two aspects are fundamental antipodes: (1) landfilling of waste and (2) considering potentially avoided emissions.

MRV is also required for NAMAs[17] or NDCs[18] respectively, though for the time being there is no harmonized or agreed method on how MRV should be implemented in this context. The recommendation for NAMAs is to apply ex-ante estimates, which should be based on the application of internationally recognized methodologies like for example CDM methodologies that quantify emission reductions and avoid double-counting (GIZ 2016). This refers to the reporting requirements for GHG inventories.

However, for a waste NAMA or NDCs for the waste sector it is very difficult for decision-makers to assess different strategies in waste management based on the GHG inventory. The emissions calculated and reported there miss to present all relevant implications of different waste management options. This is only possible with the LCA method in waste management.

Therefore, it is recommended to use both methods for MRV in the waste sector. Both are important, the LCA method to derive all impacts attributed to future waste management options, and the GHG inventory to properly report on the economy-wide progress to the UNFCCC without double-counting. **The two methods – LCA method and GHG inventory – cannot be merged to a single method to deliver both aspects. To the contrary it is recommended to develop and use an interface between the two methods.**

Therefore, the GHG emissions from waste management options should be differentiated into:

1. emissions from landfill
2. direct and avoided emissions from recycling
3. other direct emissions
4. other avoided emissions

The easiest linkage can be done for number 3. "Other direct emissions" here means direct GHG emissions from composting, anaerobic digestion with biogas use, open burning and incineration with and without energy generation and mechanical-biological treatment. These emissions are the same in the LCA results and the GHG inventory. It just would need a template with proper linkages.

Direct emissions from recycling are listed separately as they are not addressed in the GHG inventory. Nevertheless, they could be added as no double accounting would take place. Usually they are not re-ported in the GHG inventory because recycling is not identified as a relevant emission category.

Difficulties for an interface arise for the two opposed aspects "emissions from landfill" and "avoided emissions".

Avoided emissions cannot be linked directly to the GHG inventory as they are potentially avoided and

[17] Nationally Appropriate Mitigation Actions (NAMAs) are voluntary actions for reducing GHG emissions in developing countries. Following the 2009 Copenhagen Accord and the 2010 Cancun Agreements developing countries have agreed to implement NAMAs with support from developed countries. NAMAs are important tools and building blocks for the implementation of NDCs.

[18] Nationally Determined Contributions (NDCs) are part of the 2015 Paris Agreement and formalize Intended Nationally Determined Contributions (INDC) which have been previously prepared by all countries. The Paris Agreement requires each Party to prepare, communicate and maintain successive NDCs (every 5 years) that it intends to achieve.

reflect the technical substitution potential and not the market substitution potential (see chapter 13.1). In addition, usually the import/export of goods or waste materials cannot be addressed accurately due to data deficiencies. Avoided emissions from the primary production of imported goods are not reflected in the national inventory but in the inventory of the producing country. In case of avoided emissions from the LCA results it is recommended to establish an own reporting template where the results are documented for information only. This template should also provide information on the calculation basis, the most relevant input parameters and/or emission factors used with source citation and brief description.

Emissions from landfilling cannot be connected between LCA results and GHG inventory as the calculation basis is completely different. Nevertheless, linkage is possible with regard to the input parameters used for calculation like the DOC, DOCf, etc. In addition, the LCA results could also be provided in a time series. This is normally not important as all future emissions over the 100 year time horizon are attributed to the disposed waste amount and usually it is not relevant at what time these emissions will occur. However, a time series may be of help to decide on interim measurements. For example it might be important for decision-makers to assess until when the latest a currently assumed landfilling should be changed or modified to reach certain goals. A time series can be easily calculated using IPCC's k-factor (decay rate constant in 1/y for different climate zones and waste fractions). Cumulated over the time horizon the results match the LCA results.

The recommended approach can be easily implemented. Compared to that the much more important factor for MRV and LCA likewise is the data quality. Data collected, data used and calculation re-sults should be reliable and therefore an open and transparent access to information is needed. In addition data should be accurate and complete, data uncertainties and/or data gaps need to be reported transparently. Data quality is a crucial aspect not only to be able to properly assess a nations GHG mitigation but especially for E+D-countries with respect to access climate finance and participate in market mechanism, to demonstrate to donors the emission reduction and impacts, to improve trust among the parties and to address reporting obligations to the UNFCCC.

The GHG results for the 3 cities presented in this study are not accurate, because the data basis' quality is poor. Although, the order of magnitude for the GHG mitigation through diversion from landfill is robust, such GHG results would not be accepted for funding. In order to access climate funding improvement of data collection and compilation is an imperative, not only for India and Indian cities, but for most of the E+D-countries.

11 Conclusions and recommendations

11.1 From GHG results and observations

Increase of waste generation and change in waste composition resulting from population growth and rapid change in lifestyle impose difficulties on India and Indian cities to implement an integrated waste management system. The challenging situation became apparent in the 3 selected cities regarding the very difficult data situation as well as the status quo of MSW treatment.

Data is principally available like for example in Bhopal where collected waste delivered to the Bhanpura dumpsite is weighted or in Bangalore where the MBTs are equipped with a weigh bridge, and the DWCCs also weigh the delivered dry waste. However, the latter sometimes record data only in handwritten form and generally data is not available at a central level. Furthermore, data for MSW treated by the informal sector or MSW from bulk generators – apartment and high-rise blocks, hotels, canteens, etc. – are not within the scope of the municipality. This is unfortunate because MSW produced by bulk generators is assumed to be a significant share of the entire MSW. Though collected and mostly treated by private sector, relevant amounts of non-recyclable or non-marketable waste from bulk generators end up in municipal waste treatment and disposal facilities again. With no record of waste from these or other sources proper planning of SWM facilities is hampered and opportunities to improve SWM in general are lost. Including the waste from the bulk generators into the GHG balance would also potentially increase the potential net GHG savings.

The informal sector in India is a main driver for recycling activities. Informal recycling has a long tradi-tion and is well-organized and market oriented. Including these activities into the GHG balance would considerably increase the potential net GHG savings. In addition, integration into the waste management system should be accounted to help improve partly unhealthy working conditions and to create sustainable livelihoods for people working as rag pickers.

MSW treatment in the 3 cities is characterized by relevant amounts of uncollected MSW like in Bangalore and Haridwar, and by collected MSW that is landfilled untreated and often in an uncontrolled manner, like in Bhopal and Haridwar. Bangalore aims to treat collected MSW through DWCCs, MBTs and also small-scale biomethanation plants. However, many of these plants were not operational and/or not properly operating as of the data collection phase in 2016/2017. Reasons for non-operation of the MBTs were blockades from protesting citizens, power cut-off due to unpaid bills or a RDF storage fire on the one hand. On the other hand the delivered wet/mixed waste, which consists of long, rope-like textile material, regularly clogged the trommel screens and prevented proper separation of a RDF and an organic waste fraction, resulting in poor quality products which were not and/or hardly marketable.

Apart from data gaps and technical problems, the administrative capacity the high staff turnover as well as the lack of funds and systems to cover the costs are posing significant challenges for the planning, organization implementation and control of municipal solid waste management in Indian cities.

But in many ways India is proceeding well in the right direction. Important national and regional programs support ULBs financially to some extent. The revised MSW Rules 2016 stipulate proper waste management and the 2016 MSW Manual aids ULBs to develop municipal solid waste management plans. The many initiatives on grass root level ranging from NGO to other private or voluntary activities can and should be integrated in waste management planning. To address climate protection the Indian Rules and Regulations already tackle the most crucial aspect. Especially mandatory diversion from landfill, which is considered in the optimization scenarios, has the most relevant impact on climate change.

Waste data and waste stream monitoring are of major importance, not only to allow reliable GHG results but also to know the amounts and properties of the waste in order to plan integrated waste management systems. The situation on data and information as it had been encountered in 2016/2017 im-pedes accuracy for the GHG results computed in this study. The status quo and the scenarios had to be based on various assumptions and therefore, all GHG results should not be regarded as an accurate reflection of the reality in all 3 Indian cities and therefore are nonbinding. Nevertheless, the order of magnitude for the GHG mitigation through diversion from landfill is robust. In addition, the GHG scenarios show the possibilities of climate protection through integrated waste management. However, to achieve this some major obstacles need to be addressed:

1. For Municipalities it is essential to know the <u>total waste amounts generated</u> including MSW from bulk generators to plan sufficient treatment capacity. They need to establish a comprehensive data collection system and monitoring system for MSW. Data on waste collection should be recorded digitally and reported to a central register. This could range from collecting and compiling weighing data at plant level to data from NGOs and private sector to the inclusion of data collected through web-based applications for the private and/or informal sector like for example with the app "I got garbage". The collectors use the app to report the mass collected.

2. The waste composition, the properties of the waste, is essential to decide on suitable treatment options. For example the results for Bhopal reveal that cities with a high share of organic waste should put in great efforts on source segregation of wet/organic waste and good professional composting (or modern anaerobic digestion) to gain quality compost. In addition the treatment of wet/mixed waste, which remains after source segregation, in a MBT is likely to result in further net GHG debits. Representative sampling and analysis as proposed in the MSWM Manual 2016 are a prerequisite to plan and implement the waste management system.

3. In addition, it is strongly recommended to undertake pilot test with collected MSW before implementing a waste treatment plant to prevent failures as observed in the MBT in Bangalore. To know the waste helps to plan adequate separation steps and produce quality products.

4. Especially the production of quality compost does not need high-technology units but source segregation of wet/organic waste and good professional operation. That this is feasible had been proven for a long time by the KCDC plant in Bangalore, before a change in the waste man-agement system in Bangalore converted it to treat wet/mixed wet waste. Best practice for low GHG emission composting is described e.g. in a German guideline (BGK 2010). It would be helpful to have corresponding guidelines in English at hand to support operators to identify the most crucial aspects for low GHG emission operation.

5. Another aspect of importance especially for Bangalore are the relevant amounts of MSW generated, which end up in an uncontrolled manner at dump sites and/or queries, causing significant problems like the burning Bellandur lake in February 2017. Aside from the need to improve MSW collection these sites need to be identified, secured and further dumping should be prevented. This can be either done through mapping by task forces or remote sensing may be a possibility.

6. For future optimization source segregation as proposed in scenarios 1 and 2 is seen as key to clean waste fractions allowing quality products and high recycling rates. Though, technical sorting solutions may be an alternative for dry waste, at least organic waste should be collected separately and not mixed with other residual waste as this would contaminate the organic fraction irreversibly. Realization of source segregation is surely easier in small cities but also possible in large/mega cities at least at less densely built-up or higher income areas. Source segregation does not need high investments into equipment, but sufficient containers and suitable transport facilities. The main investment must be on personal and on educational training for citizens and also for waste collectors. Incentives for the citizens to source-separate should be taken into account.

7. In general, for future optimization a stepwise implementation of waste management options is recommended as demonstrated with the scenarios 1 and 2. In Haridwar the newly constructed SWM facility could be used for a strictly separated 2 line operation of source segregated wet/organic waste and of wet/mixed waste. In Bangalore some of the existing MBTs could be rededicated to process wet/source segregated organic waste only as was done in the past in the KCDC plant. This could be done again in some plants while the rest continue processing the remaining wet/mixed waste. For Bhopal new plants are necessary.
   Although scenario 2 does not aim to achieve the maximum mitigation potential possible, both scenarios 1 and 2 reveal considerable GHG mitigation effects. Both scenarios are considered feasible and comparably easy to implement on a cost-effective basis. However, the proposed modern anaerobic digestion plants or application of WtE technology proposed for scenario 2 need higher investments, which are not likely to be covered by revenues from sales of biogas

and compost only, or produced energy respectively. Other financing sources like cost-covering waste service fees should be considered as unavoidable. Fee levels should be social-just, and could be supported and decreased through favorable energy tariffs, application of producer responsibility and/or additional funds from product charges and through support programs from national and/or state level.

8. Additionally, at least for medium-sized and large/mega cities waste incineration after source separation and treatment of waste is regarded necessary. It is also an option for RDF fractions which cannot be used for co-incineration in cement kilns or for rejects and impurities from pretreatment. Generated and collected MSW in India usually is not suitable for incineration due to a low heating value. Here again, suitable fractions need to be identified by analysis and the waste stream entering the incineration facilities need to be customized according to the operation parameters of the plant.
   Cluster WtE and/or co-incineration in WtE plants for agricultural residues are options for smaller waste streams because WtE plants need a minimum throughput of suitable material to be economically viable. This may be reasonable for the remaining wet/mixed waste fraction for Bangalore as demonstrated in scenario 2b. However, if the assumptions on the waste characteristics are true, from a climate protection point of view it does not matter which of the two concepts – scenario 2a with MBT and quality RDF for co-incineration in the cement industry or scenario 2b with WtE plant – the city opts for.

9. In general, municipalities should examine possibilities for cooperation with other cities or other economic sectors to realize e.g. a cluster WtE concept, co-incineration in cement kilns, co-incineration in WtE plants for agricultural residues or co-processing of organic waste in biogas plants using energy crops and/or agricultural residues. However, these cooperation need stable, longer-term commitments on all sides based on clear contracts. In any case for waste incineration a proper flue gas cleaning is mandatory to respect human health concerns. Incinerator operation must comply with the emission standards of the SWM Rules 2016, and also the co-processing of MSW in industrial or agricultural sectors always needs to examine first if this is compliant with environmental needs.

10. The leaders of municipal cooperation, cities and states need to be convinced to put more emphasis on development plans for the waste sector and to dedicate adequate resources to the improvement of MSW management. There is still need for more and other types of funding. Financial means are needed and may be provided to some extend by implementing the requirement of the MSW Rules 2016 for user fees for solid waste management. Additionally climate mitigation related funding should be considered for developing appropriate and climate friendly integrated waste management systems and infrastructure.

11.2 From extrapolation for city clusters

The extrapolation of the GHG results for city clusters displays that the potential contribution of small cities to national GHG mitigation is relevant and should not be neglected.

Large-scale projects implemented in (mega) cities definitely have significant climate mitigation potential. Internationally, and in climate mitigation and finance, mega-cities get attention and have opportunities to get support for their large-scale projects as the volumes required are matching requirements of banks and financiers. Large and medium sized cities may have the advantage of a centralized administration, of a high population share and more capacity for planning and implementation of technical and financially feasible projects than smaller cities.

However, in smaller cities the opportunities for sound source segregation might be higher, which is the prerequisite for an efficient treatment of recyclables and organic waste. It might be relatively easy to motivate the local population, to communicate the benefits to the stakeholders and to apply use fees for better services. The technologies applied in cities of that scale, like composting, might be faster to implement, easier to operate and the quality compost produced might be better marketable via regional outlets in the area and the surrounding rural communities. In addition, they could create income and/or employment opportunities as a co-benefit. Capacity building is necessary, but does not demand the degree of highly specialized engineering skills as a large-scale incineration or a modern anaerobic digestion plant would require. So, if smaller cities would get access to programs, which offer more standardized technical solution, capacity building and financial support, and are enabled to implement waste management solutions on their scale, they could considerably contribute to national climate mitigation efforts.

Besides addressing mega- and medium-size cities it could therefore be considered by decision-makers to enlarge the support for smaller cities in the waste sector. Such a program should cover training on methods for waste sampling and waste analyzing in the smaller cities as well as, for example, the development of a standard construction pattern for biological treatment. An ideal effect would be if companies would specialize on such 'small scale solutions' like for example composting as this would give a merit of order effect for other cities. These projects could be bundled on regional or national level programs allowing financing institutions and climate funds to get involved, because the financing scale is large enough. By redistribution of funds, smaller cities could be able to overcome some of the initial challenges to develop their waste management systems.

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13 Annex

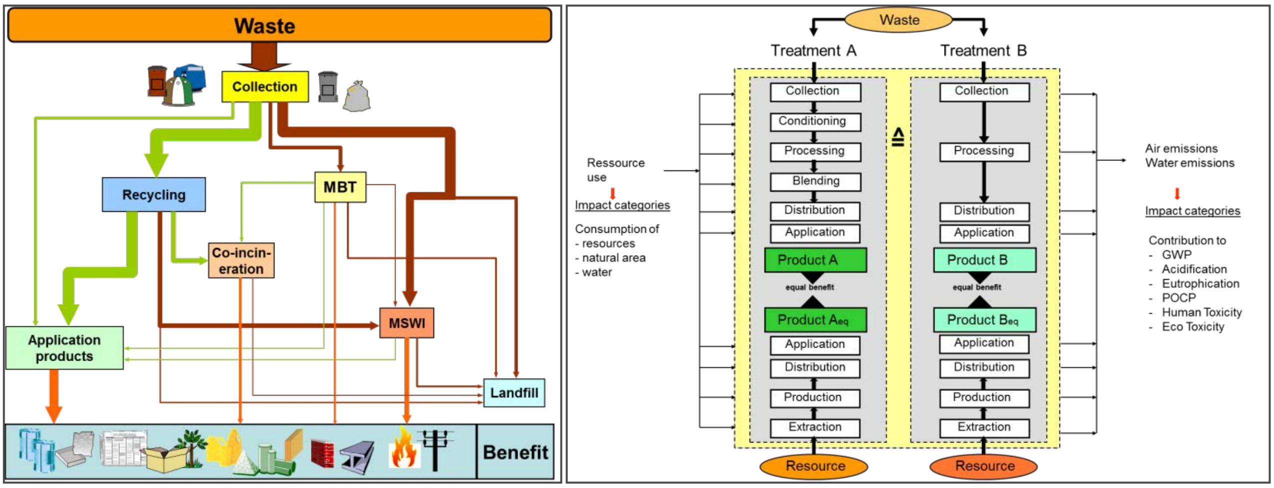
13.1 Annex I: LCA method in waste management

Life cycle assessment (LCA) is a methodology that seeks to identify the environmental impacts related to a product, service or system from a holistic standpoint that includes all known potential environmental impacts and follows the product, service or system from "cradle to grave". The life cycle includes all known processes in the stages of extraction of raw materials, production, use and disposal. The LCA method is standardized in ISO 14040/44. The LCA in waste management is based on this standard with certain amendments.

13.1.1 System boundaries and system comparison

The LCA method in waste management is focused on the waste sector. All waste management activities – both direct emissions as well as potentially avoided emissions through substitution of primary products and energy – are included. All emissions from waste treatment are related to the waste amount considered (e.g. landfilling 100 year time horizon). The results represent mitigation potentials offering decision-making aid to politic, public authorities and industry.

Figure 41: left: Flow chart of a waste management system; right: System boundary and comparison rules in LCA visualized



To assess the waste sector the boundaries of the "cradle-to-grave" system begin with the waste ("previous life" excluded) and end with the final purpose of waste treatment (secondary product, energy, and disposal). The benefits of compared systems (status quo and optimization scenarios) must be equal (Figure 41). Typically, this is realized by credits for co-benefits like secondary products and energy generated. These credits are calculated as negative values and represent mitigation potentials because it cannot be proofed that the assumed substitution of primary products or energy really takes place. In general, LCA practitioners should use the most likely substitution process. Nevertheless, for example in case of recycling the technical and not the market substitution potential shall be considered. Which means 100% substitution is credited for secondary products as otherwise more recycling – and thus a lesser market substitution potential – would lead to lower GHG mitigation.

13.1.2 Other methodological agreements and data used

In the following relevant methodological agreements are listed and explained briefly. Comprehensive descriptions are to be found in previous studies (Dehoust et al. 2010, Vogt et al. 2015).

- Crediting for energy produced is performed using the average approach (grid electricity); in previous studies the marginal approach was used which assumes that 'additionally' produced energy from waste generally substitutes fossil fuel. However, especially for comparison with mid- or long-term optimization scenarios the marginal approach tends to overestimate the GHG saving potential considering the climate change goals and energy transition. The emission factors equally used in this study for energy demand and credits are:

- emission factor for electricity generation in India: 928 g CO_2eq/kWh,
- emission factor for heat generation: 334 g CO_2eq/kWh.

- In optimization scenarios no changes are made to emission factors for energy supply, neither for demand nor for credits, to ensure that differences by comparison with the status quo are the result of changes in waste management and not in the energy sector.
- Possible carbon sinks are not considered in the GHG scenarios for the 3 cities. Usually the carbon sink – where it is quantifiable – is stated only in sensitivity analysis or reported for information only due to considerable uncertainties attached to the long-term storage of biogenic carbon. In this study the data for the 3 cities itself are associated with high uncertainties. Therefore, the carbon sink is not addressed.
- Recycling is calculated using the harmonized emission factors provided in Vogt et al. (2015) as no national or regional data is available.
- Composting and anaerobic digestion are calculated using emission factors derived from measurements in Germany.
- Also due to the lack of regional or national data, landfilling is calculated using IPCC's default values (IPCC 2006):
  - DOCf = 50% (average value for all waste that may partly contain lignin)
  - Methane content = 50 Vol%
  - Methane correction factor (MCF):
    managed disposal sites – anaerobic = 1
    unmanaged disposal sites – deep (> 5 m waste) and/or high water level = 0,8
    unmanaged disposal sites – shallow (< 5 m waste) = 0,4
    uncategorized disposal sites = 0,6
  - Oxidation factor (OX):
    default value = 0%
    covered (e.g. soil, compost), well-managed landfill site[19] = 10%
  - Gas collection efficiency:
    default value = 0%, if no data are available
    default value = 20%, if estimated based on the installed gas collection system
- Fossil and regenerative carbon content as well as heating value of the waste generated are calculated based on the waste composition; the standard parameters used are shown in Table 13. The values for organics, paper, plastics and textiles are derived from analysis results in (Weichgrebe et al. 2016) for the West Zone in Bangalore and are used for all 3 cities as no other data is available for India. The value for "others" is taken from (Dehoust et al. 2010) for Germany and the EU. Glass, inert and metals neither contain carbon nor contribute to energy generation.

[19] Default for OX according to IPCC is 0%; the value of 10% is justified for covered, well-managed landfills.

Table 13: Standard parameters for waste fractions

	total C % by mass	share regenerativ C % total C	heating value kJ/kg
Organics	21	100	4779
Paper	25	100	9123
Plastics	50	0	23525
Textiles	31	56	14066
Glass	0	0	0
Inert	0	0	0
Metal	0	0	0
Others	21	53	7800

13.1.3 Impact assessment of 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 GWPs for the 100-year time horizon are used in this study. The 100-year time horizon is nearest to the approximate lifetime of CO_2 in the atmosphere, and thus represents best the overall impact of CO_2, which are responsible for 55-60% of anthropogenic radiative forcing according to IGSD (2013). In addition, the GWP100 is used to calculate the national emission inventories in compliance with the Kyoto Protocol. Table 14 shows the most recent GWP100 values of IPCC's 5th assessment report (IPCC 2013) which are used in this study. For comparison also the GWP100 values from IPCC (1995) are presented which were first used for national reporting under the Kyoto Protocol.

Table 14: Global warming potential for the 100-year time horizon of the most important greenhouse gases

Greenhouse gas	CO_2-equivalent value (GWP100) [kg CO_2eq/kg]	
Carbon dioxide (CO_2), fossil	1	1
Carbon dioxide (CO_2), regenerative	0	0
Methane (CH_4), fossil	30	21
Methane (CH_4), regenerative	28	18.25*
Nitrous oxide (N_2O)	265	310
Source:	(IPCC 2013)	(IPCC 1995)

*Excluding the stoichiometrically calculated GWP of fossil CO_2 after conversion of methane in the atmosphere

Carbon dioxide and methane emissions are distinguished according to their origin. Regenerative methane (from the conversion of organic substances) has a lower GWP than methane from fossil sources, because regenerative carbon dioxide – produced from the methane over time as a result of oxidation in the atmosphere is treated as climate-neutral.

13.2 Annex II: Tables with sectoral GHG results

Table 15: Sectoral GHG results for Bangalore in tons CO_2eq/a

Sectors	Status quo	Scenario 1	Scenario 2a	Scenario 2b
Debits				
open burning	5852			
dump/landfill	216889			
home composting	590			
landfill fire	10899			
not processed + dumped	142183			
biomethanation	350			
MBT	182411	239974	137124	
WtE				155707
composting plant		28759	53683	53683
AD plant			10743	10743
DWCC/MRF	84993	107802	107802	107802
Credits				
MBT		-315463	-228335	
WtE				-221452
composting plant		-32330	-60348	-60348
AD plant			-53862	-53862
DWCC/MRF	-122059	-337792	-337792	-337792
Net	**522107**	**-309049**	**-370985**	**-345519**

Table 16: Sectoral GHG results for Bhopal in tons CO_2eq/a

Sectors	Status quo	Scenario 1	Scenario 2
Debits			
landfill	167988		
landfill fire	3250		
MBT		19481	8727

composting plant		11504	13421
AD plant			3474
cluster WtE		20306	20306
recyclables		10798	10798
Credits			
MBT		-12119	-7510
composting plant		-12932	-15087
AD plant			-13465
cluster WtE		-30878	-30878
recyclables		-40643	-40643
Net	**171238**	**-34483**	**-50857**

Table 17: Sectoral GHG results for Haridwar in tons COR2Req/a

Sectors	Status quo	Scenario 1	Scenario 2
Debits			
scattered			
landfill	28090		
landfill fire	1283		
MBT		4091	2878
composting plant		5125	8125
recyclables		1845	2767
inert material*			0
Credits			
MBT		-9206	-6345
composting plant		-5747	-5747
recyclables		-13638	-20458
inert material*			0
Net	**29374**	**-17530**	**-21780**

* silt excluded from MSW in scenario 2, inert material does not cause GHG emissions from disposal

13.3 Annex IV: Terms and definitions

Table 18: Extract of the established excel glossary

deutsch	Abkürzung für Tabellen o.ä.	english	abbrevation for e.g. tables	Synonym	
Vergärung, anaerobe Verfahren	AV	anaerobic digestion	AD	biomethanation	anaerobic treatment of source separated / segregated organic waste
Asche	Asche	ash	ash		inerts from fuel combustion for cooking/heating
Biogasanlage	BGA	biogas plant	BGP	anaerobic digestion plant	
Mülltonne	Tonne	waste bin	Bin	garbage can, dust bin	used for curbside collection; collect system; collection from households; volume in Germany between 60-240 liters
Biologische Behandlung	Bio.beh	biological treatment	BioT		aerobic and anaerobic biological treatment
Bringsystem	BS	bring system	BS		inhabitants bring their waste to containers, bring banks, bottle banks (see waste container)
Offene Verbrennung	O.Verbr	open burning	BURN open	(landfill fires)	burning of waste in backyards, doorsteps, streets, on landfill sites
Bau- und Abbruchabfälle	B&A-Abf	Construction & Demolition Waste	C&DW		
Blockheizkraftwerk	BHKW	combined heat and power plant	CHP		stationary combustion engine generating electricity and heat from gaseous or liquid fuels
Mitverbrennung/ Mitverbrennungsanlage	Mitverbr.	co-incineration/-incinerator	Co-inc.	(co-processing)	incineration of waste in industrial facilities (cement kilns, power plants) as fuel substitute
Informelle Abfallsammler/-sammlung	Samml (inf)	informal sector waste collection	COLL (inf)	door-to-door / doorstep waste collectors, wastepickers, scavengers, rag pickers	informal sector persons/institution collecting waste
Informelle Abfallsammler/-sammlung: Container/Straße	Samml (inf)-Cont	informal sector waste collection: container/street	COLL (inf)-Cont		informal sector stakeholder(s) which pick waste fractions from containers or streets

deutsch	Abkürzung für Tabellen o.ä.	**english**	abbrevation for e.g. tables	Synonym	
Informelle Ab-fallsammler/-sammlung: Haustür	Samml (inf)-Tür	informal sector waste collection: door-to-door	COLL (inf)-DtD		informal sector stakeholder(s) which collect waste fractions source segregated from households
Informelle Ab-fallsammler/-sammlung: Deponie	Samml (inf)-Dep	informal sector waste collection: landfill site	COLL (inf)-Lf		informal sector stakeholder(s) which pick waste fractions from landfill sites
Sammelsystem	SammlSys	collection system	COLL-Sys		type of collection: informal-formal; collect-bring system; bins-containers-others; motorized-manually
Müllfahrzeug	Samml-Fhzg	Collection vehicle	COLL-Veh	garbage truck	
Wurmkompostierung	Komp (Wurm)	Vermiculture, Ver-micomposting	COMP (verm)		composting of source segregated organic waste with special worms; produces high quality compost suitable as ferti-lizer/humus
Biologische Behand-lung der Organik aus Mischmüll	Komp-Mischm	Composting of mixed waste	COMP-mix		aerobic treatment of organics from mixed waste
Bio-/Grünabfall-Kom-postierung	Komp-Bioabf	Composting of segre-gated organics	COMP-segr		Only for separately collected/source-segregated waste, aero-bic biological treatment
Abfallcontainer	Cont	waste container	Cont		used for bring system; standing in the streets/on public places; volume in Germany typically 5-10 cbm
Öffentliche Verrich-tung der Notdurft	DEF	open defecation	DEF		defecation in open areas because/where (public) restrooms are missing
Beseitigungswege	Bes.wege	disposal methods	D-M		waste treatment without substitution benefit; landfill and in-cineration without energy recovery
abbaubarer organ-ischer Kohlenstoffge-halt	DOC	degradable organic carbon	DOC		share of carbon in waste that is biologically degradable (IPCC)
Abbaurate des DOC	DOCf	decomposed de-gradable organic car-bon	DOCf		fraction of DOC which decomposes (IPCC)

Table 19: MSW definition

Definition MSW	Germany (EU)
	Our study
MSW	household waste:
	paper
	glass (and pottery and china)
	plastics
	metal
	green/garden waste (wood, bushes, grass, plants)
	kitchen + canteen waste (biowaste)
	textiles
	rubber and leather
	bulky waste (home furnishings: furniture, mattresses, woody objects, carpets/floorings, bicycleparts)
	ash (from fuel for cooking/heating)
	inerts (e.g. dirt, dust, ...)
	commercial/institutional waste similar to domestic waste:
	kitchen/canteen waste (food waste)
	park waste
	market waste (meat, fish markets, fruit, vegetable markets)
	street sweepings
	waste from slaughter houses
	animal carcasses
	fecal matter (solid; from streets, public areas)
not considered	not considered
hazardous/problematic MSW	batteries, rechargable batteries
	fluorescent tubes

Definition MSW	Germany (EU)
	solvents
	acids
	leachings (bases)
	fotochemicals
	pesticides
	paints, print colours, adhesives
other MSW	bio-medical waste
	E-waste
	end-of-life vehicles
	sewage sludge
construction & demolition waste	*mainly inert (concrete, rubble, etc.)*
industrial waste	*In most developing countries industrial wastes are included in the municipal solid waste stream*
	therefore, it is difficult to obtain separat data

13.4 Annex V: Data collection tool

Table 20: Data collection tool – Sheet 'Waste data'

City Name										
n/a = not applicable	**Governing areas:**	1	2	3	4	5	6	7	…	**total**
	Code	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
waste generated	W/gen									
District information										
population										
housing typology										

City Name										
collection										
Collection frequency										
Collection coverage										
Average distance to site	in km									
Collection fee	specify: per ton, …									
Method used for fee collection										
Type of collection										
collection system	COLL-Sys									
Collection vehicle	COLL-Veh									
Waste collected		TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
informal sector waste collection	COLL (inf)									
informal sector waste collection: container/street	COLL (inf)-Cont									
informal sector waste collection: door-to-door	COLL (inf)-DtD									
informal sector waste collection: landfill site	COLL (inf)-Lf									
segregated waste collected	W/segr									
segregated waste collected (informal)	W/segr (inf)									
segregated organic waste composted	W/segr-comp									
segregated organic waste anaerobically digested	W/segr-AD									
Provide information source										
How and when was the data collected/obtained?										
pre-treatment		TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
Pre-treatment for transport, recycling	PRETr									
sorting	SORT									
sorting by hand	SORT (hand)									
mechanical treatment	MT									

City Name										
Provide information source										
How and when was the data collected/obtained?										
non-treated (privately treated) waste		TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
open burning	BURN open									
(organic) waste eaten by animals	W/animal									
segregated waste fed to animals	W/feed									
waste scattering/scattered	W/scat									
Provide information source										
How and when was the data collected/obtained?										
disposed of waste	**D-M**	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
mechanical-biological stabilization	MBS									
mechanical-physical stabilization	MPS									
mechanical-biological treatment	MBT									
open MBT	MBT (open)									
landfilling	Landf.									
unmanaged landfill, unmanaged disposal site	LF-unmgd.									
managed landfill	LF-mgd.									
sanitary landfill	SLF									
Provide information source										
How and when was the data collected/obtained?										
treated/managed waste	**T-M**	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
anaerobic digestion	AD									
anaerobic MBT	MBT (anaerob)									
biological treatment	BioT									
dry fermentation	FERM (dry)									

City Name										
wet fermentation	FERM (wet)									
Composting of mixed waste	COMP-mix									
Composting of segregated organics	COMP-segr									
Vermiculture, Vemicomposting	COMP (verm)									
Recovery	RECOV									
Recycling/Recycler	RECY									
informal sector recycling/recycler	RECY (inf)									
co-incineration/-incinerator	Co-inc.									
waste to energy	WtE									
Provide information source										
How and when was the data collected/obtained?										
MSW composition		TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD	TPD
Specify source of sample (waste generated/uncollected/collected/ at landfill/to incineration)										
household waste	W/HH									
mixed waste	W/mix									
Bio-degradable waste	W/bio-degr.									
paper, cardboard										
organic waste	W/org									
Garden/green waste	W/gr									
Kitchen/Canteen Waste (households)	W/K+C_HH									
Recyclables										
glass (and pottery and china)										
plastics										
mixed plastics										

City Name											
polyethylen	PE										
polypropylen	PP										
polystyrene	PS										
polyethylene terephthalate	PET										
polyvinylchloride	PVC										
metal											
ferrous metals											
non-ferrous metals											
aluminium											
copper											
others											
textiles											
rubber and leather											
bulky waste (home furnishings: furniture, mattresses, woody objects, carpets/floorings, bicycleparts)											
Others											
nappies (diapers)											
ash	ash										
inerts (e.g. dirt, dust, ...)											
household and similar waste	W/HH+S										
Kitchen/Canteen Waste (commerce)	W/K+C_HH+S										
Garden and Park waste	W/G+P										
market waste (meat, fish markets, fruit, vegetable markets)											
street sweepings											
waste from slaughter houses											

City Name										
animal carcasses										
fecal matter (solid; from streets, public areas)										
SHARE OF PROBLEMATIC WASTE										
<u>Provide information source</u>										
<u>How and when was the data collected/obtained?</u>										
Waste characterisitics	**unit**									
Specify source of sample (waste generated/uncollected/collected/ at landfill/to incineration)										
water content ("moisture")	% wet waste									
dry matter content	% wet waste									
degradable organic carbon (DOC)	% wet waste									
total carbon content	% wet waste									
fossil carbon content	% wet waste									
decomposed degradable organic carbon (DOCf)	% DOC									
lower heating value (LHV)	MJ/kg wet waste									
<u>Provide information source</u>										
<u>How and when was the data collected/obtained?</u>										

Table 21: Data collection tool – Sheet 'landfill'

City Name	*n/a = not applicable*						
Landfill	Code	unit	A	B	C	…	total
Name							
Facility location - address							
Type of landfill							
unmanaged landfill, unmanaged disposal site	LF-unmgd.						

City Name	*n/a = not applicable*						
Landfill		unit	A	B	C	…	total
managed landfill	LF-mgd.						
sanitary landfill	SLF						
Current status							
starting year of waste disposal							
closed since							
Who operates the landfill?							
Capital cost (at construction)		INR					
Nominal tipping/gate fee		INR/t					
Has landfill contracted its carbon credits? Any CDM projects?							
Design capacity of the landfill		m^3					
Volume of waste in place		m^3					
Tonnage of waste in place		tons					
Area covered landfill		acre					
Average height of landfill body		m					
Remaining area for waste disposal		m^2					
Current quantity of waste recieved		TPD					
How is the waste quantified at the landfill?							
Waste accepted for disposal							
MSW		TPD					
Hazardous waste		TPD					
Incineration Ash		TPD					
Construction debris		TPD					

City Name	*n/a = not applicable*						
other		TPD					
Approximate quantity of waste lost by landfill fire		% current waste quantity recieved					
How often is the cover applied to open waste							
Approximate surface area of the working face		m^2					
Electricity demand		kWh/t waste treated					
Fuel demand		kWh/t waste treated					
Type of fuel							
Landfill gas							
Is flue gas monitored properly?							
Any gas vented passively to the atmosphere?							
Is there a landfill gas collection system installed?							
Starting year of gas recovery after commencing the landfill							
Closing year of gas recovery after commencing the landfill							
LFG collection rate		m^3/hr					
Efficiency of gas collection		%					
Methane content of collected gas		% by volume					
Treatment of collected landfill gas							
flare		m^3/hr					
Energy generation							
Quantity of electricity generated		kWh/a					
Efficiency of electricity recovery		%					

City Name	*n/a = not applicable*						
Percentage of electricity use for onsite operation activities		%					
Quantity of heat generated		kWh/a					
Efficiency of heat recovery		%					
Value of energy generated (If resold)		Use appropriate unit					
Other (i.e. boiler, heater, pipeline injection)							
Potential/viable LFG utilization options or inter-ests - are any industries nearby?							
<u>Informal activities</u>							
Number of waste pickers (total, females, children)							
Waste pickers organisations							
Do waste pickers have legal access to the landfills and dumps?							
Are waste pickers required to use health and safety equipment, such as gloves and respiratory masks?							
<u>Removal of recyclables (paper, metals, plastics, …)</u>							
insert type		TPD					
insert type		TPD					
…		TPD					
Price per tonne of recyclables							
insert type		INR					
insert type		INR					
…		INR					
<u>Provide information source</u>							