RESEARCH PAPER

Modelling approaches for greenhouse gas emissions projections

Waste sector

ISSUE 42
Modelling approaches for greenhouse gas emissions projections: Waste sector

Waste sector

Date: 04/11/2015
Country: South Africa

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The following citation should be used for this document:
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INTRODUCTION

The MAPS programme (www.mapsprogramme.org) is a collaboration amongst developing countries to establish the evidence base for long-term transition to robust economies that are carbon-efficient and climate-resilient. MAPS thus endeavours to contribute to ambitious climate change mitigation that aligns economic development with poverty alleviation. Central to MAPS is the way it combines research and stakeholder interest with policy and planning. At the time of writing the programme was at the advanced stages of being rolled out in four countries in Latin America: Peru, Colombia, Chile and Brazil.

This paper focuses on the analysis conducted to provide country level information on potential emissions under a business-as-usual or reference scenario, and under scenarios in which greenhouse gas (GHG) mitigation options are implemented. The focus of this paper is the waste sector, with complementary papers having been produced for other sectors. The paper provides a brief overview of the approaches used in the individual countries. It then describes the modelling framework, the drivers of emissions, data used, main assumptions and a summary of how mitigation approaches were considered in the analyses. The final section presents a comparison of the different approaches used, including some of the pros and cons encountered.

All four countries included emissions from the management of solid waste and the treatment of wastewater in their analyses. These two contributors to emissions from the waste sector are considered separately.
BRIEF OVERVIEW OF THE INDIVIDUAL COUNTRY PROCESSES

A full review of the individual country processes is outside of the scope of this paper, although the processes are documented extensively elsewhere. In summary:

- The MAPS programme in Peru is known as PlanCC (http://www.planccperu.org/). The first phase of PlanCC, which ran from April 2012 to July 2014, sought to generate qualitative and quantitative evidence on climate change mitigation opportunities. The process considered six sectors; including agriculture, energy, forestry, industrial processes, transport and waste. The analysis used 2009 as a base year with the projections starting in 2010, and considered an emissions reference scenario and potential mitigation opportunities for the period to 2050 (PlanCC, 2014).

- In Colombia, the mitigation study documented in this paper was conducted by the Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM is the Spanish Acronym) (Universidad de los Andes, 2015). The study was based on 2010 base year emissions (2010) calculated to develop the national GHG emissions inventory (IDEAM et al, 2015). One baseline scenario (2010-2050) was established, projecting the emissions from the national GHG emissions inventory, in the case of the waste sector accounting for different waste management practices (solid waste disposal, incineration, and water treatment). Two mitigation scenarios were proposed based on different levels of mitigation action for each sub sector (Universidad de los Andes, 2015).

- Phase 1 of the Chilean analysis, known as MAPS Chile (www. http://mapschile.cl/), ran from the end of 2011 until the middle of 2012. This first phase of the project developed a baseline for the period 2007 to 2030 which included the “natural” evolution of technologies in the different sectors. Phase 1 also considered possible trajectories of future emissions to align with the recommendations of the IPCC in terms of what is required from a scientific perspective. Phase 2, which ran from 2012 to 2014, developed an emissions baseline for the period 2013 to 2030, conducted an analysis of individual mitigation actions and presented a set of mitigation scenarios (MAPS Chile, 2014).

- The MAPS Programme related work done in Brazil during 2014 focussed on modelling a reference emission scenario for the period 2010 to 2030, and looking at the potential for reducing emissions through implementing mitigation actions. The reference emissions scenario was developed assuming that current mitigation government policies are implemented. The two additional mitigation scenarios considered the case when new mitigation policies and measures were introduced, with the second mitigation scenario being more ambitious than the first (IES Brasil, 2015).

Note that the remainder of this paper is based on the references provided in brackets for each of the individual countries unless indicated otherwise, and references are not provided again, for the sake of readability.
MODELLING OF EMISSIONS FROM SOLID WASTE MANAGEMENT

The same generic approach to modelling emissions from solid waste management was used in all four countries. Firstly, projections of the future volumes and compositions of solid waste were developed – with composition being important as it is the organic fraction of the waste stream that results in generation of GHG emissions. Waste generation is directly linked to population growth. For solid waste from the residential sector, an increase in GDP/income levels also results in a per capita increase in waste generation, as well as a change in waste composition (although these changes were only considered in certain countries). Waste volumes and compositions are then linked to GHG emissions by considering current waste management options and those that could potentially be used in the future. Finally, the approach to projecting mitigation potential is considered in different ways by the different countries. The following sections provide an overview of the approaches used to model solid waste projections and mitigation of the emissions from the management thereof.

1. Peru

1.1.1 Modelling approach

For the calculation of emissions projections from solid waste management in Peru it was assumed that only waste generated in urban areas that is managed in sanitary landfills or dumps would give rise to methane emissions. In 2010 74.11% of the population lived in urban areas, a figure which was projected to grow to 86% by 2050. Although not stated explicitly in the reports, organic waste in rural areas may have been considered to be most likely to be fed to cattle or used to make compost, and hence these emissions would be much lower than for urban waste, and are excluded.

Projections of waste generation in the urban residential sector were obtained by multiplying the current rate of waste generation by projections of the growth in population and of growth in waste generation per capita. Waste generation per capita is, in turn, linked to GDP growth. Projections of commercial waste generation and waste arising from markets were calculated as a simple multiplier of residential waste generation, using a factor obtained from international literature. Residential, commercial and market waste were added together to give total solid waste generation.

Two options were considered for the management of the waste; sanitary landfills and dump sites. The IPCC 1996 GHG emissions inventory guidelines were used to convert waste disposed via these management options to GHG emissions (IPCC, 1997). The 1996 guidelines were chosen in preference to the 2006 guidelines to ensure consistency with the approach used in the recently compiled GHG inventory for Peru. It is noted that the 1996 guidelines do not use a first order decay function, unlike the 2006 IPCC guidelines that were used by some of the other countries (IPCC, 2006). This could be considered as a serious limitation to the results of the analysis, causing an underestimation of emissions. The reason why this approach was used, however, is that the first order decay needs historic data for a number of years, which is not available in Peru. Extrapolations have to be done for many cities with information from cities with similar profiles, for a specific year.

Using the calculation approach specified in the 1996 guidelines, the annual GHG emissions from waste disposal (in tonnes of CO₂ per annum) are calculated by multiplying total municipal solid waste disposed of via each disposal route in each year (in tonnes per annum) by the following:

- a methane correction factor (MCF), which is specific to the disposal route used;
- the fraction of degradable organic material in the waste;
• the fraction of organic material that actually degrades;
• the fraction of carbon that is released as methane;
• a conversion ratio;
• the global warming potential of methane.

The data for each of these parameters is discussed in the following section.

1.1.2 Data sources

Waste generation and disposal information used in the construction of the 2009 GHG inventory was used to populate these parameters in the base year. Data for the projection of generation per capita was obtained from studies conducted by the Ministry of Environment (MINAM, 2010). In 2009 the generation per capita was 0.56 kg/person/year. An annual increase of generation per capita 5.6 % was assumed until 2020, after which generation per capita remained constant to 2050 at a level of 1.025 kg/person/year. Urban population projections used in the waste sector emission projections were consistent with those used across the sectors in the MAPS process (PlanCC, 2014).

It was assumed that the waste stream from the commercial sector and markets was equivalent to 50% of the waste from the residential sector. This assumption was based on a previous study conducted on management of waste in Latin America and the Caribbean.

The IPCC guidelines provide default values for the MCF for different disposal routes. The average MCF for Peru was calculated using the ratio of population served by each of the disposal options. MCFs were calculated using three different periods: 2009–2015, 2016 and 2017–2050. The change of MCF in 2016 was to account for the planned establishment of a number of new sanitary landfill sites in 2016/2017. For the remaining factors (fraction of degradable organic material in the waste, fraction of organic material that actually degrades, fraction of carbon that is released as methane and the conversion ratio), the information provided in the 1996 IPCC guidelines is used. The guidelines provide a value for fraction of degradable organic material in the waste for Peru, while the other factors are not country specific. It is noted that through using this approach, the underlying assumption is that waste composition remains unaffected by a growth in GDP. Finally, a global warming potential of 21 was used in line with the 1996 guidelines.

1.1.3 Mitigation actions

Five mitigation actions were included in the Peruvian study:

• construction of sanitary landfills with capture and flaring of methane;
• construction of sanitary landfills with capture of methane for use in electricity generation;
• construction of semi-aerobic sanitary landfills;
• production of compost and segregation of organic materials; and
• segregation and recycling of inorganic solid waste.

The same approach was used for modelling mitigation actions across all of the sectors in the Peruvian study. A mitigation abatement cost curve (MACC) was developed for each of the options by calculating the difference between the net costs when implementing the measure and subtracting the costs of the business as usual (BAU). The MACC curves also took into account income potential of the mitigation options. The net cost was divided by the difference between the BAU emissions for the sector and the sectoral emissions when implementing the option. Here the total for all periods of implementation of the option, including the base year and 2050, were included. The final report presented each of the options, the assumptions, the level of ambition, assumptions about period of implementation, costs and emission.
savings, a qualitative comment on co-benefits and considerations surrounding the viability of the option.

Mitigation actions were combined into four different scenarios. These were as follows:

- a “savings” scenario, which looked purely at emissions savings. Here 47 mitigation actions were included;
- a “sustainable” scenario, which included mitigation actions that achieved a minimum of 40 million tonnes of CO₂e savings, and at the same time offered social and environmental co-benefits (this was the scenario focused on the final reports);
- a “rapid” scenario, which included 14 mitigation actions that could be implemented quickly; and
- an “all actions” scenario.

It is noted that the methodology on how the mitigation options were selected is not presented in detail in the reports, although it is assumed that this would have been via stakeholder consultation. Furthermore, it is not clear whether interactions between the mitigation actions were considered. For example, if a component of the waste is treated via composting, does this reduce the mitigation potential of landfills – as less organic material is now being sent for landfilling?

1.1.4 Summary for Peru

Table 1 presents a summary of the main features of the modelling approach used for Peru for emissions from solid waste management.

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td>• Only urban waste was considered.</td>
<td>• Five mitigation actions were considered: construction of sanitary landfills with capture and flaring of methane; construction of sanitary landfills with capture of methane for use in electricity production; construction of semi-aerobic sanitary landfills with capture and flaring of methane; production of compost and segregation of organic materials; and segregation and recycling of inorganic solid waste.</td>
</tr>
<tr>
<td></td>
<td>• Drivers of waste generation in the residential sector are population growth and generation of waste per capita. No changes in waste composition with changes in GDP were considered.</td>
<td>• A MACC was developed for each option using a bottom-up approach. Both costs and revenues were considered.</td>
</tr>
<tr>
<td></td>
<td>• Commercial and market waste volumes were calculated as a multiplier of residential waste generation, using a factor obtained from the literature.</td>
<td>• Four scenarios were presented, although it is not made clear how scenarios were constructed and whether interactions between the mitigation actions were considered.</td>
</tr>
<tr>
<td></td>
<td>• Two waste disposal options were used; sanitary landfills and dumps.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emissions from these disposal options were calculated using the 1996 IPCC guidelines, using default emission factors and the IPCC provided spreadsheets.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emissions are estimated for both of the management options and the results are aggregated to the national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Models were built using Microsoft Excel.</td>
<td></td>
</tr>
</tbody>
</table>

1.2 Colombia
1.2.1 Modelling approach

In the Colombian models, the primary source of emissions considered were those generated from municipal solid waste that were disposed of to different types of solid waste disposal sites, as well as waste that burned in open burning. In addition, emissions linked to thermal treatment of specific hazardous industrial and institutional waste were accounted for.

Emissions associated with solid waste disposal were linked to the amount of solid waste disposed annually in landfills in each of the 32 departments of the country. The amount of waste disposed of is linked to the population of each department, and the per capita waste production. The model makes provision for differences in waste composition, waste disposal practices and waste generation per capita for the different departments, although as discussed below, there were difficulties in obtaining waste composition data for all of the departments. All three of the variables are assumed to remain unchanged throughout the analysis period, and are not affected by changes to GDP as for some of the other countries. Four waste disposal options were considered; un-managed shallow, un-managed deep, managed, and uncategorised disposal sites.

The approach to modelling emissions from waste consigned to landfills and dumping was based on Chapter 3 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5\(^2\), which has at its core a first order decay model. The emissions baseline was established based on the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) report, which contains the Tier 2 analyses for the GHG emissions inventory in year 2010 (IDEAM et al, 2015). The IPCC model allows the projection of waste emissions to 2030. Based on the growth rate of the emissions obtained from this model, the annual emissions for the period 2031-2050 were projected.

Emissions from solid waste incineration and open burning of waste were also determined by projecting the values reported by the IDEAM for the base year (2010). The country’s current incineration processes are used only for managing hazardous waste, and this is considered as the appropriate treatment for this category of waste. Emissions associated with incineration accounted for 2% of total emissions from the waste sector in that year. As waste incineration is not proposed as a mitigation action in Colombia, the emissions from solid waste incineration and open burning of waste from 2012 to 2050 were projected using the annual growth percentage of the Colombian industrial sector and the base year 2010 reported by IDEAM\(^3\).

1.2.2 Data sources

As mentioned above, the emissions baseline was the 2010 GHG inventory that was established by using the IPCC 2006 guidelines. At national level a number of gaps exist in the information that is required for completing the models. For this reason, some of the parameters used in the models were calculated or modified based on official or referenced information. For example, the values of the per capita waste generation for twenty-four of the thirty-two departments were modified due to concerns about inconsistent information. These adjustments are only relevant for the projections, rather than the base year calculations.

To establish projections of annual waste generation, data on the population growth of each Colombian department reported by National Administrative Department of Statistics (DANE) for the years 2005-2020 was used. Based on the population reported for these years, departmental projections were made to obtain the information required by the model for the years 2021-2030. Waste generation per capita was also evaluated based on departmental information from the Superintendent of Public Services (SSPD) for the years 2005-2012. Although the per capita values for each department


\(^3\) It is noted that although open burning of municipal solid wastes is conducted, the fossil carbon comes from sources such as textiles, diapers and plastics. Hence the decision to link it to industrial growth, rather than population. The contribution from this source was considered to be marginal at the national level.
remained constant through 2013-2030 evaluations, data was analysed, and information for some of the departments was modified, before the projections were made. Solid waste disposal practices data was also obtained from SSPD.

Waste characterisation data was obtained from the Biogas Colombian Model developed by the United States Environmental Protection Agency. Some of the data was adjusted before the emissions were calculated.

For the parameters required by the model, such as degradable organic carbon, methane generation rate constants, delay time before the anaerobic decay begins, the fraction of methane developed in gas, and the oxidation factor, the default IPCC values were used for each of the thirty-two departments. No methane recovery from landfill was accounted for in the models.

The data used to establish the emissions related to waste burning and incineration for the year 2010 was obtained from the National Report on Waste Generation and Management of Hazardous Waste (IDEAM, 2012) and from SSPD. Incineration values were projected based on the projected growth of the industrial sector in Colombia.

1.2.3 Mitigation actions

Composting, recycling, waste incineration and methanotrophy on landfill final caps (note 4) were included in the analysis of solid waste emissions mitigation potential. Each of these actions is allocated a date of implementation and degree of penetration in the mitigation models. Two mitigation scenarios were constructed as follows:

Under Scenario 1, mitigation of 50.8% of emissions by 2030, and mitigation of 54.3% of emissions by 2050 (note 5), would be achieved by the following actions:

a. Composting of the 20% of organic waste produced nationally, avoiding its disposal to landfills. The implementation timelines were as follows:
   i. 2016-2019: Composting of 5% of the organic waste.
   ii. 2020-2024: Composting of 10% of the organic waste.
   iii. 2025-2030: Composting of 20% of the organic waste.
   iv. 2030-2050: Maintaining 20% of organic waste disposal avoidance during the period.

b. Gradual increase in paper and cardboard recycling from 2016, achieving an increase of 7% by 2030.

c. Capture and flaring of 50% of the methane emitted from landfills. This implementation begins gradually in 2016 and achieves the full 50% by 2030.

d. Growing methanotrophic organisms on final landfill cover layers to reduce the fugitive methane emissions.

Under Scenario 2, mitigation of 21.2% of the emissions by 2030, and of 22.1% by 2050, would be achieved by:

a. Composting 20% of the organic waste produced nationally, avoiding its disposal to landfills. Implementation rates used are as follows:
   i. 2020-2024: Composting of 5% of the organic waste.
   ii. 2025-2030: Composting of 10% of the organic waste.
   iii. 2030-2050: Maintaining 10% of organic waste disposal avoidance during the period.

b. Capture and flaring of 20% of the methane emitted from landfills. The implementation is implemented gradually beginning in 2016 and achieving the full 20% by 2030.

A MACC curve was constructed for each of the mitigation options.

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4 Methanotrophy is the introduction of methanotrophic micro-organisms on the landfill final layers. These micro-organisms oxidise the fugitive methane emissions on this layer and prevent them from reaching the atmosphere. Various studies on methanotrophic activity and methane flow rates have been conducted on Doña Juana Landfill (Colombia’s biggest landfill) by the Universidad de los Andes.

5 It is noted that these emissions savings were achieved by the combination of waste and wastewater mitigation action. The mitigation actions in the wastewater sub-sector that contributed to this savings are discussed in the relevant section for Colombia.
### 1.2.4 Summary for Colombia

Table 2 presents a summary of the main features of the approach used for Colombia for modelling emissions from solid waste management.

**Table 2: Main features of the modelling approaches used for Colombia for emissions from solid waste management**

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombia</td>
<td>• Only municipal waste was considered.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Waste generation was linked to population and per capita generation, but not to GDP growth.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Different waste composition and per capita generation data was used based on the 32 departments of the country. The composition used in each department was the composition documented in the Modelo Colombiano de Biogas. Some adjustments were made on few departments, due to inconsistent data.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Five different disposal options were considered: managed landfills, unmanaged landfills (deep and shallow), uncategorised disposal, and burning of waste.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Calculation of emissions from waste disposal was done using IPCC 2006 for each department separately. This model makes use of a first order decay equation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Calculation of emissions from incineration and open burning of waste was done using IPCC 2006 at a national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• This was coupled with local data when this was available.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emissions are estimated for different waste management options and the results are aggregated to the national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Four mitigation options were considered: composting, recycling, waste incineration and methanotrophy on landfill final covers or caps.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• For each option, an implementation scenario was designed which considered a year of commencement and a penetration.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• A MACC curve was then constructed for each mitigation option.</td>
<td></td>
</tr>
</tbody>
</table>
1.3 Chile

1.3.1 Modelling approach

In modelling the baseline for Chile, as in the case of other countries, a projection of waste generation rates is first made. As with Peru, waste generation predictions were a function of both population growth and growth in GDP. Waste from both cities and villages are considered.

To account for the difference in generation between the Santiago Metropolitan Region and other regions, historical data for waste generation between 1996 and 2010 was used to plot a trend in the relationship between rates of waste generation. Between these years a steady decline in this ratio has been seen, from a value of around 1.8 in 1996 to just over 1.2 in 2010, meaning that waste generation rates in the other areas are approaching those of Santiago Metropolitan Region. This is due to the high income of this region in comparison to other regions. The trend was assumed to continue into the future until rates in the regions matched those in the metropolitan areas. In other words, the calculation in each year was made as follows:

\[ GPC_{RM} = I \times GPC_{OR} \]

Where:
- GPCR = Generation per capita in the metropolitan regions
- GPCOR = Generation per capita in the other regions
- PobRM = Population in the metropolitan region
- PobOR = Population in the other regions

Given that climatic conditions like humidity and temperature affect the decomposition of waste and the quantity of methane that is generated, it was necessary to determine projections of waste generated and disposed of in each region of the country. This value was calculated by multiplying the GPC for each region by the regional population in the region.

The percentage of waste sent to the different disposal locations in the different regions in 2012, adjusted for the planned establishment of new sanitary landfills, was used to project total future volumes of waste sent to different disposal locations.

The modelling of GHG emissions also included provisions for changes in waste composition. The approach to projecting waste composition is discussed in Section 1.3.2.

Once the waste generation projections had been calculated for each of the regions, the 2006 IPCC guidelines were used to project the generation of emissions from the three different types of management options: sanitary landfills, other landfills and dump sites, and composting. In addition to considering future waste disposal, the models also included emissions from waste that had been disposed of prior to 2012. The first order decay model as described in the IPCC guidelines was used to calculate the emissions from the different types of disposal sites. Under this model, the volume of methane that is generated depends on:
- the type of landfill that is used;
- the percentage of degradable organic carbon (DOC);
- the decomposable DOC;
- an oxidation factor; and
- a reaction constant that depends on climatic factors.

In calculating emissions from landfills, an adjustment was made for landfill gas capture. At the start of the modelling period (2013), it was assumed that for mature projects the fraction of methane captured in relation to the total methane emitted remained constant. For projects being executed but in the early stages of development, a minimum capture required to avoid explosions was included in the baseline, with any further capture being considered as a mitigation measure.

Emissions produced in composting were calculated using the methodology and default factors found in the IPCC guidelines in the chapter “Biological Treatment of Solid Waste”. Only emissions of N₂O and CH₄ were included in the calculation of emissions from composting. For the baseline, it was assumed that the ratio of waste sent to composting relative to that sent to landfill remained constant at 2011 levels.

In addition to emissions from general waste management, emissions from incineration of hospital waste and human body parts were included in the Chilean emissions projections. The emissions depend on the total mass of waste incinerated and the fossil fuel contents thereof. For calculating the emissions from this category of waste, the IPCC Tier 1 approach was used. Historical data on the rate of generation was used to determine a relationship between waste generation and time, which was then used to project future emissions. Only CO₂ emissions were calculated.

The waste (and wastewater) model was built on a software package called Analytica with a full description of the model being presented in an Annex to the Chilean project’s final report.

### 1.3.2 Data sources

For determining the link between volume of waste generated and GDP, data from various OECD countries was analysed to determine the link between GDP and generation per capita per annum. A regression was used to fit a log function to the data, and thereby ascertain the elasticity of waste generation with GDP. GDP projections used in the Chilean MAPS process more broadly were then used to provide a projection of waste generation per capita in the future. To obtain total waste generation, this figure was then multiplied by the population projections per region. Population growth projections were aligned with those used broadly in the MAPS Chile process.

For the base year’s waste composition, the data in the IPCC 2006 guidelines for South America as a whole was used. In future projections the waste composition was adjusted to allow for a reduction in the proportion of organic content in the waste stream as the economy develops. It was assumed that by 2030 the composition of the waste stream in Chile would be similar to that of Southern Europe (this region was chosen due to the climatic, geographical and cultural similarities with Chile). To obtain the proportion of each component of the waste stream in each year, the values were extrapolated between those for South America (which were assumed to be the same as those for Chile in 2013), and those for Southern Europe (which were assumed to represent those for Chile in 2030). It is important to note that the results show that the food per capita generation is almost constant. Post-2030, the proportions of the different components of the waste stream were kept constant.

It is important to note that the waste stream composition used for the base year from the IPCC guidelines relates to
municipal solid waste that is sent to final disposal, and therefore excludes the waste that is sent for recycling and composting. To calculate the composition of the waste that is generated (rather than disposed of), the figures were adjusted to account for recycling and composting, using rates for 2012.

The following data sources were used for the parameters required in the first order decay model:

- The methane correction factor for different types of disposal sites, oxidation factors and decomposable degradable organic carbon (DOC) were obtained from the IPCC 2006 guidelines.
- The IPCC guidelines also provide figures for percentage of DOC for different components of the waste stream (paper, textiles, food waste, etc). The proportions of these fractions of the waste stream were calculated using procedures described previously.
- The value of the reaction constant (k) for the different regions was obtained from a study for Chile published by the Inter-American Development Bank (BID, 2003).

The capture rate for landfill gas capture included in the baseline was 6% (except for those projects which generate electricity from the captured methane), being the average value included in CDM Project Design Documents as a minimum capture level.

For incineration of hospital waste and human body parts a combination of the default factors for the Tier 1 approach in the IPCC 2006 guidelines and some locally relevant parameters were used. The locally relevant parameters were those used during the determination of the 2007 baseline in Phase 1 of the project, and included fraction of dry material in the waste, fraction of carbon in the dry material, fraction of fossil carbon as a proportion of total carbon and the oxidation fraction.

1.3.3 Mitigation actions

Mitigation actions considered in Chile included:

- Composting;
- increasing recycling through the law on extended producer responsibility;
- bio-digestion;
- capture and flaring of landfill gases;
- injection of biogas into the natural gas system;
- electricity generation from gas from landfill sites;
- mechanical and biological treatment (where waste is separated and the biological component composted or fermented to reduce volumes of waste sent to landfill); and
- thermal treatment of waste.

As with the other countries described, for each option the capital and operating costs, income generation and GHG mitigation potential was calculated, based on a start and end year for the option. In Chile, unlike the other countries, three discount rates were considered in calculating the net present value of the costs: two that represented social discount rates and a third that was considered to be more representative of that in the private sector.

The measures were evaluated individually and then combined into “mitigation scenarios”. These scenarios, defined by the experts in the process, correspond to the simultaneous implementation of several measures. Five distinct mitigation scenarios for waste were considered, each with different levels of implementation of the mitigation actions. During the construction of the scenarios, consideration was given to the fact that not all mitigation actions could be implemented simultaneously, as implementing one option reduces the potential for implementing the next. For example, composting
reduces the organic waste sent to landfill, and hence the amount of methane and electricity generation potential. Mitigation options were thus ordered into a hierarchy that takes into account cost effectiveness and competitiveness, with the most cost-effective being considered first.

1.3.4 Summary for Chile

Table 3 presents a summary of the main features of the modelling approaches used for Chile for emissions from solid waste management.

Table 3: Main features of the modelling approaches used for Chile for emissions from solid waste management

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>• Methane generation from disposal of waste from cities and villages in sanitary landfills and landfills or dumps is included, as was N₂O and methane from composting.</td>
<td>• Mitigation actions included composting, increasing recycling, bio-digestion, capture and flaring of landfill gases, injection of biogas into the natural gas system, electricity generation from gas from landfill sites, mechanical and biological treatment and thermal treatment.</td>
</tr>
<tr>
<td></td>
<td>• Emissions from incineration of hospital waste and human body parts are also included in the projections.</td>
<td>• For each option capital and operating costs, income generation and GHG mitigation potential was calculated, based on an initiation and termination year for the option.</td>
</tr>
<tr>
<td></td>
<td>• Waste generation is linked to population and to GDP growth. However, the obtained results show that the food per capita generation is almost constant.</td>
<td>• Five different implementation scenarios were then constructed, each relating to different levels and combinations of implementation of mitigation actions.</td>
</tr>
<tr>
<td></td>
<td>• Waste composition is suggested to change from current composition to that of Southern Europe by 2030. Post-2030, the composition of waste was assumed to remain constant.</td>
<td>• Consideration was given to the fact that not all mitigation actions could be implemented simultaneously, as implementing one option may reduce the potential for implementing the next.</td>
</tr>
<tr>
<td></td>
<td>• A regional approach was taken in Chile, where current disposal used in each of the regions is considered, as well as any plans for new sanitary landfills.</td>
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</tr>
<tr>
<td></td>
<td>• A first order decay model, as detailed in the 2006 IPCC guidelines, was used to determine emissions from the different waste management options.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emission factors and constants were mostly those in the IPCC guidelines. The exception here was the value of the reaction constant, where a value specific to each of the individual regions was included.</td>
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</tr>
<tr>
<td></td>
<td>• Emissions from composting were calculated using the methodology and default factors found in the IPCC guidelines in the chapter “Biological treatment of solid waste”. Only emissions of N₂O</td>
<td></td>
</tr>
</tbody>
</table>
### Modelling Framework

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>and CH₄ were included.</td>
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</tr>
<tr>
<td></td>
<td>• Emissions are estimated for the different waste management options and regions, and the results are then aggregated to the national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• CO₂ emissions from incineration of hospital waste and human body parts depend on the total waste incinerated and the fossil fuel contents.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The IPCC Tier 1 approach was used for these emissions, with some locally determined parameters (fraction of dry material in the waste, fraction of carbon in the dry material, fraction of fossil carbon as a proportion of total carbon and the oxidation fraction).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Historical data on the rate of generation was used to determine a relationship between generation of this waste and time.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• All waste models for Chile were built in Analytica.</td>
<td></td>
</tr>
</tbody>
</table>

### 1.4 Brazil

#### 1.4.1 Modelling approach

The Brazilian study only considers emissions up to 2030. The reference scenario includes emissions that may occur with full or partial implementation of public policies that are already part of government initiatives until 2010. These included an increase in collection rates, an increase in the proportion of waste that is sent to sanitary landfill (including an increase in recycling of dry waste), capture and burning of biogas, a reduction in the number of dumps and controlled landfills, and an improvement in the management of industrial waste. For each of these options a judgment was made as to the extent to which these policies would be implemented in order to construct the reference case.

As with other countries, GDP and population were the drivers of waste generation. It was recognised that GDP per capita influences both the waste generation rates per capita, as well as the composition of the waste stream. Per capita generation of waste is linked to GDP through a trend relationship (details of which are not presented in the report). The proportion of organic waste in the waste stream is noted to decrease as income increases, due to increased consumption of processed foods. At the same time, an increase in income results in greater buying power and an increase in recyclables in the waste stream. How these factors were incorporated into the study is unclear. The differences between rural and urban populations in terms of waste generation were also noted.

In projecting emissions from landfills, the study uses the first order decay model as specified in IPCC (2006).

In addition to landfilling, the study also considered organic waste that is treated by biological treatment and thermal treatment, both controlled incineration and open pit burning. For thermal treatment, it was recognised that only non-biogenic carbon should be considered, so emissions from thermal treatment were calculated per waste type.
1.4.2 Data sources

Previous studies were used to obtain waste generation rates per capita, collection efficiencies and GDP projections, while common assumptions about population growth used in the broader MAPS process in Brazil were used for projecting waste generation rates into the future.

For the first order decay model, the IPCC (2006) default factors were used, with the exception of the fraction of the carbon emitted as methane and the oxidation factor that were obtained from a study by the Brazilian Ministry of Science, Technology and Innovation. The IPCC 2006 default factors were also used to calculate emissions from organic waste that is treated by biological treatment and thermal treatment, both controlled incineration and open-pit burning.

1.4.3 Mitigation actions

After considering a long list of mitigation actions, the scenario building team (SBT) decided to focus on only two mitigation actions for the two mitigation scenarios: destruction of methane from operating landfills using flares; and destruction of methane from dumps and remediated landfills. The difference between the two mitigation scenarios was the extent of expansion into small, medium and large cities. For each of the mitigation options in each of the scenarios the tonnes of GHG emissions avoided per year and the cost per tonne in 2030 were calculated.

1.4.4 Summary for Brazil

Table 4 presents a summary of the main features of the modelling approaches used for Brazil for emissions from solid waste management.

Table 4: Main features of the modelling approaches used for Brazil for emissions from solid waste management

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>• GDP and population were used as drivers of waste generation. &lt;br&gt; • The study considers landfilling, organic waste that is treated by biological treatment and thermal treatment, with the latter including controlled incineration and open-pit burning. &lt;br&gt; • For landfilling, the first order decay model as specified in IPCC (2006) is used to estimate emissions. &lt;br&gt; • The IPCC 2006 default factors were used for the first order decay model, with the exception of the fraction of the carbon emitted as methane and the oxidation factor for which local data was available. &lt;br&gt; • The IPCC 2006 default factors were also used to calculate emissions from organic waste that is treated by biological treatment and thermal treatment, both controlled incineration and open pit burning.</td>
<td>• Mitigation options considered were destruction of methane from operating landfills using flares; and destruction of methane from dumps and remediated landfills. &lt;br&gt; • The difference between the scenarios was the extent of penetration in small, medium and large cities. &lt;br&gt; • Mitigation potential per year and cost in 2030 was modelled.</td>
</tr>
</tbody>
</table>
2 MODELLING OF EMISSIONS FROM WASTEWATER MANAGEMENT

As with solid waste, domestic wastewater generation is linked to population. Emissions from domestic wastewater treatment are a function of the technology used for treatment, volumes treated and protein in the diet (although this is not considered in all of the countries). Once the composition and volumes of waste and wastewater are determined, emissions associated with their management can be projected. Note that in this section the modelling approach and data sources are considered together.

2.1 Peru

2.1.1 Modelling approach and data sources

For the calculation of the emissions from domestic wastewater, the percentage of wastewater produced that is treated is first determined. Historical data on the increase in percentage of wastewater treated between 2000 and 2011 was plotted and a trend line obtained (the data fits a linear trend very closely). This linear trend is assumed to continue up to 2050 by which year 96% of wastewater generated will be treated. The second is the growth in population, which is consistent with the assumptions used for all sectors in the MAPS analysis as described previously.

Using these parameters, the spreadsheet model based on the IPCC guidelines of 1996 (with the default model parameters) is then used to calculate the emissions associated with domestic wastewater management. Methane production was thus based on a constant production of degradable organic material per person per year throughout the analysis period. This figure was multiplied by the percentage of wastewater treated as described in the previous paragraph, a “methane conversion factor for the handling system” for which a value of 0.8 is used (i.e. no allowance for type of wastewater handling system nor any changes to the domestic wastewater treatment infrastructure), and the maximum methane-producing capacity in kg CH₄/kg biological oxygen demand (BOD), for which a consistent figure of 0.6 was used throughout the analysis period.

Nitrous oxide production was based on an average protein consumption, which remained constant throughout the analysis period.

For industrial wastewater, data was analysed for wastewater propagated in the production of five products that contribute 82% of the organic emissions from industry. The historical trend in increase in production of these products from 2001 to 2010 was used as a starting point, and for each subsequent year a 10-year rolling average for the previous years was used to estimate production to 2050. The production of these products was then multiplied by the wastewater production per tonne of each product, and then by the kg COD/m³ in each product’s wastewater stream. This provides the organic load in kg COD/annum from each product. This value is then summed and multiplied by a constant release of kg CH₄/kg COD to give methane emissions. The relevant methane global warming potential is applied to provide the total emissions from this sub-sector. The approach and emission factors used for emissions calculations are consistent with the IPCC guidelines.

2.1.2 Mitigation actions

Three mitigation options were considered here:

* installation of systems for methane capture from existing anaerobic lagoons with flaring of the methane;
* installation of systems for capturing methane from existing lagoons, with energy generation using the methane; and,
• installation of anaerobic digestion units for treatment of sludge in treatment plants, and capturing of methane for electricity generation.

The approach to modelling mitigation options in wastewater management is as described for solid waste management in Section 1.

### 2.1.3 Summary for Peru

Table 5 presents a summary of the main features of the modelling approaches used for Peru for emissions from wastewater.

Table 5: Main features of the modelling approaches used for Peru for emissions from wastewater management

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td>• Population growth is considered as a driver of volume of wastewater treated.</td>
<td>• Three mitigation options were considered: methane capture and flaring from anaerobic lagoons; methane capture and energy generation from anaerobic lagoons; and anaerobic digestion for treatment of sludge in treatment plants, and methane capture for electricity generation.</td>
</tr>
<tr>
<td></td>
<td>• The historical trend in growth in percentage of wastewater treated is assumed to continue.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The spreadsheet model prescribed by the IPCC guidelines of 1996, with the default model parameters, is used to calculate the emissions associated with domestic wastewater management.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Here methane production is based on a degradable organic material per person per year throughout the analysis period, in wastewater that is captured for treatment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Nitrous oxide production is linked to average protein consumption, which is assumed to remain constant throughout the analysis period.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emissions from industrial wastewater treatment were considered for five principle products that contribute 82% of the organic emissions from industry.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The historical trend in increase in production of these products from 2001 to 2010 was used as a starting point, and for each subsequent year a 10-year rolling average for the previous years was used to estimate production to 2050.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Emissions from industrial wastewater treatment were also calculated using the IPCC guidelines.</td>
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</tbody>
</table>
2.2 Colombia

2.2.1 Modelling approach and data sources

Emissions from both domestic and industrial wastewater management were included in the modelling of emissions from the wastewater sub-sector. For domestic wastewaters, methane (CH$_4$) and nitrogen oxide (N$_2$O) were determined. For industrial wastewater only methane emissions were calculated.

The IPCC guidelines were used by the IDEAM to establish the wastewater emissions inventory in 2010, using the Tier 1 approach. Methane emissions from domestic wastewater treatment in 2010 were determined based on DANE’s population report (DANE, 2012), specific information obtained from reports on different treatment plants across the country, information from SSPD, and various IPCC default values including the methane correction factor for each type of treatment or discharge and the maximum methane producing capacity. Using this 2010 value, the DANE’s annual population growth rate was applied, obtaining the annual emissions for the years 2011-2020. Based on the growth rate of the emissions obtained for these years, the annual emissions for the period 2031-2050 were projected. It is noted that no sludge removal was taken into account.

Nitrous oxide emissions were calculated using the spreadsheets developed by the IDEAM, which contained country specific information, and where information was not available the IPCC default values were used. Country specific data was obtained from the Food and Agriculture Organization (FAO) statistics and DANE’s report (DANE, 2012). The default values were used for parameters such as the emission factor and the fraction of nitrogen in protein. The emissions were projected taking into account DANE’s population 2010-2020. The value of annual protein consumptions was maintained constant throughout. Based on the growth rate of the emissions obtained, the annual emissions for the period 2031-2050 were calculated.

For the industrial sector, emissions calculated by IDEAM using the IPCC guidelines for the year 2010 were used as the baseline, and this value was projected to the year 2050, based on the projected growth of the industrial sector from 2010 to 2050. Data used for the sector’s growth projections was obtained from different sources such as DANE’s Annual Manufacturing Survey for 2010\(^6\) and the Environmental Manufacturing Single Record\(^7\) for 2010. Default values were used for parameters such as the maximum methane capacity of production and the methane correction factor, according to each treatment system.

2.2.2 Proposed mitigation actions

The mitigation actions associated with domestic and industrial wastewater include capture and burning of methane, as well as the use of anaerobic ammonium oxidation (ANAMMOX) as an alternative process for domestic wastewater treatment. The timing of the latter mitigation action includes a research component prior to implementation.

The mitigation scenarios for wastewater considered (which parallel those described in the solid waste section) are as follows:

Scenario 1:

a. Capture and flaring 30% of the methane generated in domestic wastewater treatment plants by 2030, and 50% by 2050. The implementation is proposed as follows:
   i. 2016-2024: Reduction of 2.5% of the methane emitted.


\(^7\) For details see [http://www.corpouraba.gov.co/registro-unico-ambiental-rua-manufacturero](http://www.corpouraba.gov.co/registro-unico-ambiental-rua-manufacturero)
ii. **2025-2029**: Additional 15% reduction, achieving an overall reduction of 17.5% of the methane emitted.

iii. **2030**: Additional 7.5% reduction, achieving an overall reduction of 25% of the methane emitted.

iv. **2031-2050**: Gradual reduction of the methane emitted, to achieve a 50% overall reduction by 2050.

b. **20% reduction in N₂O emissions by 2050.** This reduction is associated with Anammox processes. The implementation plan that was modelled is as follows:

i. **2025-2030**: 10% reduction of the N₂O emitted.

ii. **2030-2050**: 20% reduction of the N₂O emitted.

c. **Capture and flaring of 50% of the methane generated in industrial wastewater treatment plants by 2030.**

**Scenario 2:**

a. **Capture and flaring of 30% of the methane generated in domestic wastewater treatment plants by 2030.** The implementation is proposed as follows:

i. **2016-2024**: Reduction of 2.5% of the methane emitted.

ii. **2025-2029**: Additional 15% reduction, achieving an overall reduction of 17.5% of the methane emitted.

iii. **2030**: Additional 7.5% reduction, achieving an overall reduction of 25% of the methane emitted.

iv. **2031-2050**: Maintaining 25% of methane reduction.

b. **Capture and flaring of 20% of the methane generated in industrial wastewater treatment plants by 2030.**

**Summary for Colombia**

Table 6 presents a summary of the main features of the modelling approaches used for Colombia for emissions from wastewater.

**Table 6: Main features of the modelling approaches used for Colombia for emissions from wastewater management**

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
</table>
| Colombia             | • Emissions included nitrous oxide related to domestic wastewater treatment and methane related to domestic and industrial wastewater treatment.  
                        • The Tier 1 approach from the IPCC 2006 guidelines was used for calculating the methane emissions.  
                        • Default emission factors and constants from the guidelines were used in the analysis.  
                        • Specific country activity data was also used for the calculation of domestic and industrial methane emissions.  
                        • For N₂O emissions from domestic wastewater treatment, only population growth was taken into account for 2011-2020 years. Protein consumption per capita remained constant.  
                        • Different industrial sectors were considered in the industrial wastewater analysis.  
                        • Mitigation actions considered were capture and flaring of methane, as well as the use of ANAMMOX as an alternative wastewater treatment option.  
                        • The approach to evaluation of mitigation actions was similar to that used for solid waste. |
2.3 Chile

2.3.1 Modelling approach and data sources

In 2013 in Chile, almost all of the wastewater that was generated was captured and treated in wastewater treatment plants. On this basis it was assumed in future projections that all of the wastewater that is produced is treated. Wastewater treatment emissions included in the analysis were methane and nitrous oxide from treatment of domestic wastewater, and methane from treatment of industrial wastewater. It is noted that methane levels from wastewater treatment are very low since many plants use activated sludge with aerobic degradation that has low levels of methane release. In addition, some of the water treatment plants dispose of their sewage sludge in landfills or dumps.

Methane and nitrous oxide released during wastewater treatment was linked to the technology type used in treatment. A study conducted in 2007 by the Superintendencia de Servicios Sanitarios (SISS, the government department responsible for health services) was used to provide information on the population served by different types of treatment technologies. Information on wastewater generation from 2007 was scaled by population growth figures to provide this data for the base year. Historical information has shown that growth in GDP has not resulted in an increase in adoption of more sophisticated technologies such as activated sludge. As such, it is assumed that in the future the ratios of the different treatment technologies will remain unchanged.

To calculate emissions from wastewater treatment the 2006 IPCC Tier 2 guidelines for each type of treatment was used. An average BOD value of 250 mg/l of BOD was used as the SISS has no plant-specific information. The emissions from wastewater treatment in each of the different treatment types were summed to give emissions per region.

Regarding sludge; the quantity of sludge generated at a selection of the treatment plants was known based on information compiled to construct the GHG inventory for 2012. The majority of the sludge is currently treated via anaerobic digestion. Because values for individual plants were unknown, an average value for each type of treatment was calculated, and applied retrospectively to all of the plants of a similar type. The 2006 IPCC guidelines were used to calculate emissions from sludge management, which were considered together with the emissions from wastewater management.

For industrial wastewaters, a register exists in Chile on the volume and concentration of wastewater produced in each industry sub-sector that provides the base year data. Projections of wastewater generation were based on projections of growth in industrial activity, which was provided for each sector by industry experts. Projections of organic load produced by each sector were established by multiplying the current loading by the expected growth in each sector.

The industries that generate the largest volumes of wastewater are the processing of fish, pulp and paper, and petroleum refining. A specific treatment route was allocated to each of these sectors and a general treatment to the other sectors based on expert judgment, the information used in the compilation of the GHG inventory and the IPCC guidelines.

To calculate the emissions, information on the BOD in wastewater from different sources was obtained from the Ministry of
the Environment. Where other country specific information was not available, the generic information provided in the Tier 1 analysis of the IPCC was used.
2.3.2 Mitigation actions

Two mitigation options were considered in this sector: digestion of sludge from domestic wastewater treatment and composting of sludge. The approach to analysis was the same as that used for the solid waste mitigation options described previously.

2.3.3 Summary for Chile

Table 7 presents a summary of the main features of the modelling approaches used for Chile for emissions from wastewater.

Table 7: Main features of the modelling approaches used for Chile for emissions from wastewater management

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
</table>
| Chile               | • Emissions include methane and nitrous oxide from treatment of domestic wastewater, and methane from treatment of industrial wastewater.  
                      • All of the wastewater produced in Chile is assumed to be treated in wastewater treatment plants.  
                      • Methane and nitrous oxide released during wastewater treatment was linked to the technology type used in treatment.  
                      • The IPCC Tier 2 guidelines were used to calculate emissions from wastewater treatment and sludge management.  
                      • For industrial wastewater, projections were based on growth in industrial activity.  
                      • A register exists on the volume and concentration of wastewater produced in each industry sub-sector.  
                      • The growth in organic load produced by each sector is projected by multiplying the current loading by the expected growth in each sector.  
                      • Industries that generate the largest volumes of wastewater are fish processing, pulp and paper, and petroleum refining.  
                      • To calculate emissions, information on the BOD from different sources was obtained from the Ministry of the Environment.  
                      • Where other country specific information was not available, the generic information provided in the Tier 1 analysis of the IPCC was used. | • Two mitigation options were considered: digestion of sludge from domestic wastewater treatment and composting of sludge.  
                      • The approach to analysis was the same as that used for the solid waste mitigation options described previously. |
### 2.4 Brazil

#### 2.4.1 Modelling approach and data sources

As with the other countries, emissions from treatment of wastewater are a function of population, organic load and management approach. As with the reference case for solid waste management, the starting year data wastewater production is projected into the future using population growth as a key driver. In the reference case, existing government plans for upgrading wastewater treatment facilities are incorporated into the projections and GHG emissions generation was a function of volume of wastewater captured and treated. For the mitigation cases the same wastewater treatment volumes and loading were used, but with increasing levels of ambition in terms of mitigation interventions for mitigation scenarios 1 and 2 respectively. The IPCC (2006) default factors for the different wastewater management approaches were used.

The data required to estimate $N_2O$ emissions included the nitrogen content in the effluent, population and average annual consumption of protein per capita (kg / person / year). The latter figure included consideration of human consumption, multiplied by factors that account for the unconsumed protein and the protein discarded by industries in sewage systems. For the latter factors the IPCC default values (2006) for developing countries in South America were used, being 1.1 for protein not consumed and discarded, and 1.25 for industrial and commercial sources.

Methane production associated with the treatment of industrial wastewater is accounted for by taking into account the effluents with high organic contents, treated under anaerobic conditions, as indicated by the 2006 IPCC guidelines. The industries with the greatest potential for methane generation in anaerobic treatment of their effluents are the manufacturing of pulp and paper, slaughterhouses and meat processing establishments, food and beverage industries, sugar refineries, ethanol and oil industries working with organic chemicals, laundries and dry cleaners, soap and detergents, and paint and resin factories. For the calculation of emissions from industrial waste disposal, the IPCC guidelines are also used.

#### 2.4.2 Mitigation actions

Only one mitigation option was considered for wastewater treatment in Brazil; the increased treatment of sewage in anaerobic treatment plants with flaring of methane. An expansion rate was assumed for small, medium and large cities, with the second mitigation scenario being more ambitious than the first.

#### 2.4.3 Summary for Brazil

Table 8 presents a summary of the main features of the modelling approaches used for Brazil for emissions from wastewater management.

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
</table>
| Brazil               | • Population growth is the key driver of domestic wastewater production.  
                        • In the absence of specific data on the organic load of the wastewater treated in STPs, the default value provided in the latest national GHG inventory was used. | • The only mitigation option is an increased volume of wastewater sent to sewage treatment plants. |
- \( \text{N}_2\text{O} \) is calculated based on both protein consumed and protein disposed of directly to sewers.

- Emissions from treatment of industrial wastewaters with high organic contents are assumed to be treated under anaerobic conditions.

- The industries with the greatest potential for methane generation in anaerobic treatment of effluents are the pulp and paper, slaughterhouses and meat processing establishments, food and beverage industries, sugar refineries, ethanol and oil industries working with organic chemicals, laundries and dry cleaners, soap and detergents, and paint and resin factories.

- IPCC guidelines are used for projecting emissions from both industrial and domestic wastewater treatment.

- An expansion rate was assumed for small, medium and large cities, with the second mitigation scenario being more ambitious than the first.
3 COMPARISON OF APPROACHES

The four country studies are now compared in terms of the methodologies used in modelling. Again, solid waste and wastewater are considered separately.

3.1 Solid waste

The first step in determining projections of emissions from solid waste management is to predict volumes and compositions of the waste produced. The drivers that impact on volumes and composition of waste are population and GDP. The impact of GDP is twofold. Firstly, as GDP per capita increases, overall volumes of waste generated increases. Secondly, a growth in GDP is associated with an increase in the proportion of inorganic components relative to organic components in the waste stream. There are also potential differences in regions, as well as between rural and urban areas. The approach to projecting solid waste generation in the different countries was as follows:

- In Peru it was assumed that only waste generated in urban areas would give rise to methane, from management in sanitary landfills and dumps. Projections of household waste generation were made based on population growth, and commercial and market waste was calculated using a multiplier of household waste. Generation per capita was assumed to increase until a certain year, and remain flat for the remainder of the analysis period. No adjustment was made to the composition of the waste as incomes grew.
- In Colombia, waste generation was linked to population growth only, with no link being made to a change in waste generation rate with GDP. Waste composition did not change over time, although different waste compositions were used for different areas of the country. Projections of waste generation were made on a regional basis. Some regions reported inconsistent data or data that was considered not valid, and so reported waste composition and per capita waste values were modified in some cases. The modified data was calculated based on different assumptions for each department analysed. Growth in emissions related to incineration and open burning of waste was linked to the rate of growth of the Colombian industrial sector.
- In Chile, waste generation was linked to both population growth and growth in household income. For the latter, data from various OECD countries was analysed to determine the link between GDP and waste generation per capita. The base year’s waste composition was taken as that reported in the IPCC 2006 guidelines for Latin America as a whole. For the projections, the waste composition was adjusted to allow for a reduction in the proportion of organic content in the waste stream as the economy develops to 2030. After that year the composition of waste was assumed to remain constant. Historical data was used to determine the distinction between urban and rural areas in terms of waste generation per capita. The trend was assumed to continue until waste generation in rural areas was similar to that in urban areas.
- In Brazil it was recognised that GDP influences both the waste generation rates per capita, as well as the composition of the waste stream, with per capita generation of waste being linked to GDP through a trend relationship. The proportion of organic waste in the waste stream is noted to decrease as income increases, due to increased consumption of processed foods. At the same time, an increase in income results in greater buying power and an increase in recyclables in the waste stream. The difference between generation by rural and urban populations, and the seasonal impacts on waste generation were also noted, although they are not explicit in the report.

All countries thus link waste generation to population. Furthermore, Peru, Chile and Brazil include a provision for a change in waste generation per capita with growth in GDP, which is appropriate given the historical evidence of this link. However, this has not been done in Colombia. Only Chile and Brazil acknowledged changes in waste composition with GDP, which adds a further strength to their analysis. The omission thereof is a limitation to the Peruvian and
Colombian analyses. As a final note on potential changes in waste composition with time, there are trends in production and consumption that can influence waste composition that are not necessarily linked to GDP. For example, producers may make effort to reduce packaging in products, while consumer purchases of products that are influenced by societal fashions can influence the waste that is generated. Such aspects are difficult to project, and are not considered by any of the countries.

Once the projections of volumes of waste generated had been established, annual GHG emissions were determined. The only GHG considered in all four countries was methane from anaerobic degradation of waste, which is appropriate for this sector. Different countries made allowance for different disposal options in their analyses, appropriate to the national context. In Peru, landfills and dumps were included in the analysis, with provision being made for new sanitary landfills being established. Four different disposal options were considered in the Colombian analysis: un-managed shallow, un-managed deep, managed, and uncategorised disposal sites, as per the IPCC guidelines. Waste incineration and open burning was also considered. In Chile, provision is made for methane generation from waste arising from disposal in sanitary landfills, and landfills or dumps, as well as that from composting. Emissions from incineration of hospital waste and human body parts are also included in the projections. Finally, in Brazil, the study included landfilling, emissions from organic waste that are treated by biological treatment and thermal treatment of waste, with the latter including both controlled incineration and open pit burning. It is noted that Chile made provision in their analysis for different GHG generation rates in regions with differing climatic conditions. Such a distinction would have been valuable in the other countries if data were available.

All of the countries, except Peru, made use of the procedures presented in the 2006 IPCC guidelines to calculate emissions from disposal. The 2006 guidelines are considered appropriate given that these are currently ‘state of the art’. They are preferred to the 1996 guidelines used by Peru as they incorporate a first order decay model for the decomposition of waste, which is appropriate in that it allows for emissions to be based on waste disposed of to a landfill in a particular year, and that from decomposition of waste disposed of in previous years. Only Chile and Brazil considered historical waste disposal in their analyses. The 1996 guidelines base emissions purely on waste consigned to disposal on an annual basis, thus underestimating emissions substantially. A further limitation of the 1996 guidelines is that they use a lower global warming potential for methane than the 2006 version. It is recognised, however, that the use of the 1996 guidelines in Peru was to allow for alignment with the GHG inventory approach.

In applying the IPCC methodologies, the countries primarily made use of the default data offered in the guidelines, supplementing it with local data where available. More local data would clearly have resulted in results more relevant to the local context, although in the absence of data the approach used was defensible.

In Chile, emissions from incineration of hospital waste and human body parts were calculated based on the total mass of waste incinerated and the fossil fuel contents thereof. The IPCC Tier 1 approach was used for calculating the emissions from this category of waste, although locally relevant parameters used during the determination of the 2007 baseline were included in the calculation. The approach used is considered to be defensible.

In terms of mitigation, various combinations of options that included methane capture and burning/electricity generation, composting, and recycling were considered in the various countries. Colombia also considered growing methanotrophic organisms on final landfill cover layers to reduce the fugitive methane emissions. Typically a mitigation abatement cost curve was developed for each of the mitigation options, which demonstrated the cost and emissions savings potential of each option. The MACC also accounts for consideration of year of commencement, the rate of implementation, scale of operation, location of implementation and life of the option.
Only Chile is explicit on how mitigation options were combined into different mitigation scenarios, under which the interaction between the different options is explored. While Peru also combined mitigation actions into different scenarios, it is not clear how this was done, although it is assumed to be on the basis of expert judgment. Aggregation of mitigation actions is an important consideration to explore as the extent of implementation of one mitigation option can impact on that of another. It is not clear the extent to which this was considered elsewhere in assessing the mitigation potential of individual options when combined into scenarios.

In terms of modelling software, Peru’s models were built in Microsoft Excel, while Chile used Analytica, which is a powerful tool for an analysis such as this one. In Colombia, the models were built in Microsoft Excel. For solid waste disposal sites, the spreadsheet developed by IPCC was used. For open burning and waste incineration and wastewater modelling, the spreadsheets developed by IDEAM based on IPCC guidelines were used. Brazil used a spreadsheet developed by the IPCC. Excel provides an accepted approach to modelling, although Analytica does offer some benefits in terms of versatility and reducing potential for errors.

### 3.2 Wastewater treatment

For all four countries, the calculation of emissions from treatment of both domestic and industrial wastewater began by projecting the volumes of wastewater generated and captured for treatment, and the bio-degradable organic carbon content thereof. Once these parameters had been established, the generation of emissions was a function of the treatment process used – aerobic, anaerobic, lagoons etc.

In terms of modelling, all of the countries link wastewater generation to population growth. Countries differ in terms of modelling the percentage of wastewater that is captured for treatment. Peru and Brazil both assumed an increase in the percentage of sewage that is captured for treatment, while in Chile almost all the sewage is already captured, a situation that was assumed to continue into the future. In Colombia, an increase in the volume of wastewater that is captured for treatment is only assumed in the mitigation scenarios, and not the baseline scenario.

Peru used locally derived parameters in their calculations of emissions from wastewater treatment, but all parameters were assumed to remain constant throughout the analysis period. No allowance was made for the type of wastewater handling system used, nor for any changes to the domestic wastewater treatment infrastructure. In Colombia, emissions from domestic wastewater treatment were modelled using the Tier 1 method included in the IPCC guidelines, although country specific data on activity parameters such as population, population served by different types of treatment options, industrial wastewater generation and COD for different sectors was used in the calculations. In Chile, methane released during wastewater treatment was linked to the technology type used in treatment. Historical information in that country has shown that growth in GDP has not resulted in an increase in adoption of more sophisticated technologies such as activated sludge. As such, it is assumed that in the future the ratios of the different treatment technologies will remain unchanged. Finally, in Brazil, IPCC default factors were used.

Colombia, Chile and Brazil also included nitrous oxide (N₂O) emissions in the emissions projections from domestic wastewater. These were calculated using the IPCC guidelines, although different provisions were made in the different countries for whether direct or indirect emissions or both were included in the calculation. N₂O emissions are based on protein consumption, with different assumptions being made about consumption in different countries as to whether it is likely to change with increased income levels. Brazil also accounted for protein that was disposed of to the wastewater system without being consumed.

In all four countries emissions from industrial processes were linked to the main industrial processes that give rise to wastewaters with high BOD. The current industries were analysed for discharge
volumes and BOD levels, and projections were made of growth in these industries. The IPCC guidelines were then used to project emissions from industrial wastewater treatment.

In terms of modelling mitigation, similar options are considered across the countries, although in this sector these are fewer options than in other sectors. This does reflect reality in terms of global experience. Mitigation options considered in wastewater management were as follows:

- In Peru, three options were considered: capture and flaring of methane from anaerobic lagoons, capture of methane from lagoons with energy generation and installation of anaerobic digestion units for treatment of sludge in treatment plants, and capture of methane for generation of electricity. The approach to modelling mitigation options in wastewater management is as described for solid waste (generation of MACC curves).
- In Colombia, the approach to evaluation of mitigation actions in wastewater management was similar to that used for solid waste. The options considered here were capture and flaring of methane, as well as the use of ANAMMOX as an alternative wastewater treatment option.
- In Chile, two wastewater treatment related options were considered: digestion of sludge and composting of sludge.
- In Brazil, the only mitigation option considered was increasing wastewater sent to anaerobic wastewater treatment plants with flaring of methane.

4 CONCLUSION

This paper has compared the approaches used to model emissions and mitigation options under MAPS processes in Peru, Chile, Colombia and Brazil. Although the broad approaches are similar (where generation of waste and wastewater is linked to population and in some cases GDP, and emissions are determined from the volumes of waste/wastewater treated via different routes), the details of modelling are substantially different between the countries. In this regard, some of the countries are using more recent approaches (i.e. 2006 IPCC guidelines versus 1996 guidelines), and some have more country specific information to populate the calculations. Furthermore, the number and type of mitigation actions differed between the countries.

While it is recognised that the availability of information in the different countries will limit the extent of analysis that can be conducted, using a greater degree of resolution in information and more locally specific information will clearly lead to results that are more representative of the actual emissions from a particular country.
5 REFERENCES


DANE. (2012). Estimación y proyección de población nacional, departamental y municipal total por área 1985-2020


IDEAM; PNUD; MADS; DNP; Cancillería; (2015). Primer Informe Bienal de Actualización de Colombia. Bogotá.


MAPS Chile (2014). Opciones de mitigación para enfrentar el cambio climático: resultados de Fase 2. Ministerio del Medio Ambiente; Santiago, Chile.


PlanCC (Proyecto Planificación ante el Cambio Climático) (2014). Escenarios de Mitigación del Cambio Climático en el Perú al 2050 Construyendo un Desarrollo Bajo en Emisiones