TECHNICAL PAPER

Greenhouse gas emissions from the waste sector in Argentina in business-as-usual and mitigation scenarios

Estela Santalla,* Verónica Córdoba, and Gabriel Blanco
INTELYMEC, Facultad de Ingeniería, Universidad Nacional del Centro de la Provincia de Buenos Aires, Olavarría, Argentina
**Please address correspondence to: Estela Santalla, INTELYMEC, Facultad de Ingeniería, Universidad Nacional del Centro de la Provincia de Buenos Aires, Av. Del Valle 5737, B7400JWI Olavarría, Argentina; e-mail: esantall@fio.unicen.edu.ar*

The objective of this work was the application of 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for the estimation of methane and nitrous oxide emissions from the waste sector in Argentina as a preliminary exercise for greenhouse gas (GHG) inventory development and to compare with previous inventories based on 1996 IPCC Guidelines. Emissions projections to 2030 were evaluated under two scenarios—business as usual (BAU), and mitigation—and the calculations were done by using the ad hoc developed IPCC software. According to local activity data, in the business-as-usual scenario, methane emissions from solid waste disposal will increase by 73% by 2030 with respect to the emissions of year 2000. In the mitigation scenario, based on the recorded trend of methane captured in landfills, a decrease of 50% from the BAU scenario should be achieved by 2030. In the BAU scenario, GHG emissions from domestic wastewater will increase 63% from 2000 to 2030. Methane emissions from industrial wastewater, calculated from activity data of dairy, swine, slaughterhouse, citric, sugar, and wine sectors, will increase by 58% from 2000 to 2030 while methane emissions from domestic will increase 74% in the same period. Results show that GHG emissions calculated from 2006 IPCC Guidelines resulted in lower levels than those reported in previous national inventories for solid waste disposal and domestic wastewater categories, while levels were 18% higher for industrial wastewater.

Implications: The implementation of the 2006 IPCC Guidelines for National Greenhouse Inventories is now considering by the UNFCCC for non-Annex I countries in order to enhance the compilation of inventories based on comparable good practice methods. This work constitutes the first GHG emissions estimation from the waste sector of Argentina applying the 2006 IPCC Guidelines and the ad doc developed software. It will contribute to identifying the main differences between the models applied in the estimation of methane emissions on the key categories of waste emission sources and to comparing results with previous inventories based on 1996 IPCC Guidelines.

Introduction

Methane emissions from landfills and wastewater are the main source of emissions from post consumer waste in the global greenhouse gas (GHG) emissions (Bogner et al., 2007). The entry into force of the Kyoto Protocol under the United Nations Framework for Climate Change Convention (UNFCCC) has intensified the efforts of countries to develop their GHG inventories so as to meet the established standards of transparency, accuracy, consistency, comparability, and completeness. Furthermore, both the Conference of the Parties (COP) 16 and COP 17 have decided that developing countries, according to their capabilities and the level of available support, refer to the UNFCC biannual national reports of their GHG inventories (1/COP 16, paragraph 60 c, and COP.17 Draft Decision, Outcome of the Work of the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention).

The last GHG national inventory of Argentina was developed in the year 2000 based on 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines. Methane emissions from landfills and from wastewater (including both domestic and industrial) represented 2.66% and 1.97% of the total GHG national emissions, respectively. These two sources resulted in being key categories as defined in the Good Practice Guidance (IPCC, 2002), ranking sixth and seventh in a total of nine key sources, below fugitive emissions of methane from petroleum activities and natural gas.

According to the last national census (2010), the Argentine population has reached 40 million with an urbanization rate above 90%; nearly half of the population is distributed in the five biggest urban conglomerates in the country: Buenos Aires Metropolitan Area, Cordoba, Rosario, Mendoza, and La Plata. The remaining population is disseminated across 23 provinces with population densities lower than 100 inhabitants per square kilometer. This situation generates large differences in the municipal solid waste (MSW) generation rate, which varies between 0.44 and 1.52 kg/inhabitant/day as of 2010. Based on an official study (ENGIRSU, 2005), of a total of 13,153,282 tons of MSW

Journal of the Air & Waste Management Association, 63(8):909–917, 2013. ISSN: 1096-2247 print
DOI: 10.1080/10962247.2013.800167

generated in 2010 almost 25% was disposed in open dumps or in uncontrolled sites, 30% was disposed of with partial controls, while the remaining 45% of the MSW, mostly generated in cities larger than 200,000 inhabitants, was disposed of in controlled sites and landfills.

Policies and programs implemented to date include actions that have focused on the closing of the current open dumps, prioritizing the construction of regional disposal centers, waste treatment plants for recycling of materials, and transfer stations and the construction of new landfills or the expansion of the existing ones. The national legislation regarding waste management—which has to be accomplished by municipalities—establishes recommendations for environment and human protection and sets technical requirements for disposal sites but does not set legal bound for landfill gas (LFG) capture. Over the past 8 years, 10 LFG-capture projects have been developed in Argentina under the incentive of the Clean Development Mechanism (CDM), but only two of these projects are using the LFG for energy purposes. It is noteworthy that thermal treatment of solid waste such as mass combustion or the production of a refuse derive fuel (RDF) is prohibited by law in Buenos Aires Metropolitan Area and has a high degree of rejection by the population.

Regarding domestic and industrial wastewater, while the legislation sets the limits of permitted discharge parameters, there is a weak control structure from national policy institutions, and the common practice is the storing of industrial wastewater in precarious open ponds or the application of conventional technology for domestic wastewater that usually includes filtration, settling, and polishing lagoons, but neither sludge treatment nor methane capture is included. A previous study (Santalla and Córdoba, 2012) developed to identify technologies for methane mitigation in the waste sector in Argentina demonstrated that active LFG capture and anaerobic digestion, both with energy recovery, were the most suitable technologies to be implemented in the short term.

Argentina has not yet developed a data national system for GHG inventories; therefore, there is high level of uncertainty about when the GHG emissions inventory for the sector is to be developed. Based on the national legislation that delegates the responsibility to the waste management to the municipal level, efforts are being made to develop national registries of activity data and local emission factors in the waste sector. The national GHG inventory for the year 2000 and the revisions of 1990, 1994, and 1997 inventories presented in the Second National Communication (SNC, 2005) applied the Decomposition Method and the Default Method to estimate GHG emissions in the waste sector, as suggested in the 1996 IPCC Guidelines. The Intergovernmental Panel on Climate Change (IPCC) has designed and elaborated the 2006 Guidelines for National GHG Inventories in order to provide methodologies for estimating anthropogenic emissions of GHG sources and sinks. According to these guidelines, one of the characteristics to provide quality to inventories is consistency, remarking that an inventory is consistent when the same methodology is used for the base year and the subsequent ones.

The objective of the present work was to develop a preliminary estimation of GHG emissions from the waste sector in Argentina based on 2006 IPCC Guidelines and by applying the ad hoc designed IPCC software. GHG emissions were calculated in a business-as-usual (BAU) scenario and in a mitigation scenario projected to 2030 to evaluate the impact on GHG emissions of waste sector in a 20-year time horizon. A comparison with previous inventories was also carried out to compare differences between applied guidelines.

Methodology

The first step in developing an inventory by using the 2006 IPCC Software for National Greenhouse Gas Inventories (version 1.9 from May 2011) was the developing of the inventory for an initial year, allowing the initializing of the database. The starting inventory for the Solid Waste Disposal category was set as 1950 (according to 2006 IPCC Guidelines the First Order Decay (FOD) method requires data by default for 50 year) and for Domestic and Industrial Wastewater as 1990. For all categories, the projections are prepared for 2030. The current active (default, Second Assessment Report of IPCC (SAR) Global Warming Potentials (GWPs)) CO_2 equivalent factors of 1, 21 and 310 for CO_2, CH_4 and N_2O respectively were applied. After performing all steps related to users and administration of the software, the corresponding database was developed for each waste category.

Solid waste disposal category

Activity data on solid waste disposed on land were developed from 1950 to 2030. The first official available records are from 1980; therefore, to cover past years the missing historical data were estimated based on extrapolation with population and gross domestic product (GDP) as economic drivers as suggested by the 2006 IPCC Guidelines. Data for the period 1990 to 2010 were developed based on population (obtained from the national census from 1990, 2001 and 2010, Instituto Nacional de Estadísticas y Censos [INDEC], www.indec.gov.ar) and the waste generation rate. Data for waste composition and generation rate were obtained from the SNC (2005) and the National Strategy of Solid Waste Management (ENGIRSU, 2005). The projections for the period 2011–2030 were performed by using the statistics on the waste generation rate reported by the national authority (Secretaría de Ambiente y Desarrollo Sostenible de la Nación [SAyDS], 2010) for the years 2001 to 2005, 2009, and 2010. Past (2000–1950) and future (2011–2030) data were obtained by extrapolating linear trends. To check for consistency and knowing that waste generation is associated with socioeconomic level, waste generation rate trend was compared with population growth and gross domestic product (GDP) as an economic indicator that is country specific. Trends observed in Figure 1 indicate that the variation of waste generation rate applied for the period 1950–2030 can be considered acceptable.

Methane emissions from solid waste disposal were calculated by applying the FOD model that represents the methane generation as a result of degradation of organic material under anaerobic conditions. Tier 2 of the IPCC Guidelines (2006) was applied as country-specific activity data on current and historical waste disposal based on the following equations:

$$CH_4\,Emissions = \sum_x \left[CH_4\,generated_{x,T} - R_T\right] * (1 - Ox_T) \quad (1)$$

$$CH\,generated_T = (DDOCmd_T + DDOCCma_{T-1} * e^{-k}) * (1 - e^{-k}) * F * 16/12 \quad (2)$$

$$DDOC_m = W * DOC * DOC_F * MCF \quad (3)$$

where *DOC* is degradable organic carbon in the year of deposition, fraction as Gg C/Gg waste, with default values suggested by IPCC (2006) applied for each fraction as 40% for paper/cardboard, 24% textiles, 15% food waste, 43% wood, 20% garden and park waste, and 24% diapers; DOC_F is fraction of degradable carbon content, with value applied 0.5 (default), $DDOC_m$ is mass of decomposable DOC, Gg; $DDOCma_{T\text{-}1}$ is the mass decomposable DOC (DDOCm) accumulated in landfill at the end of year (T-1), and *W* is the mass of waste disposed, Gg, obtained from population, waste generation rate, and the fraction of MSW that is disposed in landfill or controlled sites (assumed 1, since all MSW is disposed on land with different levels of control, defined through MCF factor).

Other terms in the equations are as follows: *MCF* is the methane correction factor for the anaerobic decomposition in the year of disposal, fraction. The applied values correspond to those suggested in IPCC (2006, Table 3.1, Vol. 5 Chapter 3) affected by a percentage that represents the MSW management practices along time in the country. In this sense, the period 1950–1978 corresponds to the stage of uncontrolled dumps without data records, neither of weight nor composition of waste; for this period it was applied as 100% of MCF = 0.6 corresponding to uncategorized sites. From 1978 to 2010, it was analyzed for all disposal sites of Argentina (registered and nonregistered ones) given 33% MCF = 1 (managed–anaerobic), 8.4% MCF = 0.8 (unmanaged–deep >5 m waste); 17.3% MCF = 0.6 (uncategorized site); 10.4% MCF = 0.5 (managed–semiaerobic); and 30.5% MCF = 0.4 (unmanaged–shallow, <5 m waste). These values are consistent with data of the official document ENGIRSU (2005), where it is marked that 45.1% of waste is disposed in controlled landfills (MCF = 1 and 0.8), 29.5% in semi-controlled sites (MCF = 0.6 and 0.5 as noncategorized and semiaerobics), and 25.4% to open dumps (MCF = 0.4). For the period 2010–2030 the same percentages were applied assuming similar conditions as in the baseline scenario will prevail with old landfills closed and new ones opening.

The term *16/12* is the molecular weight ratio for CH_4/C; *F* is the fraction of methane by volume in generated LFG, where a default value of 0.5 was applied; and *T* is the inventory year. In order to develop a consistent time series and according to the requirements of the FOD model, historical data as far back as 1950 was applied. The term *x* is waste category or type/material according to local data. Although there are variations in the composition of waste over time and across the country, a unique composition profile for the entire inventory was used, assuming that it represents an average of these variations (Table 1). Data were obtained from the National Strategy of Solid Waste Management (ENGIRSU, 2005).

The term R_T is the recovered CH_4, in year T, Gg. In the BAU scenario the value applied was zero. The mitigation scenario was assumed as the methane capture in landfills. A linear trend was developed based on the actual measured captured methane achieved in the period 2004–2010 through the certifications of emissions reductions under the CDM (Figure 2) and extrapolating this trend to 2030. No other mitigation options in the waste sector such as composting or recycling were considered.

The term OX_T is the oxidation factor in year *T*, fraction. The default value applied is zero. The term *k* is the methane generation rate $k = \ln 2/t^{½}$ (y^{-1}) where $t^{½}$ is the half-life time, yr. Values of *k* applied correspond to those suggested in IPCC (2006), assuming local environmental conditions such as temperature boreal, MAT (mean annual temperature) <20 C, wet (MAP/PET (potential vapo-transpiration) >1).

Table 1 summarizes the main parameters applied to estimate methane emissions in the solid waste disposal category for each year of inventory.

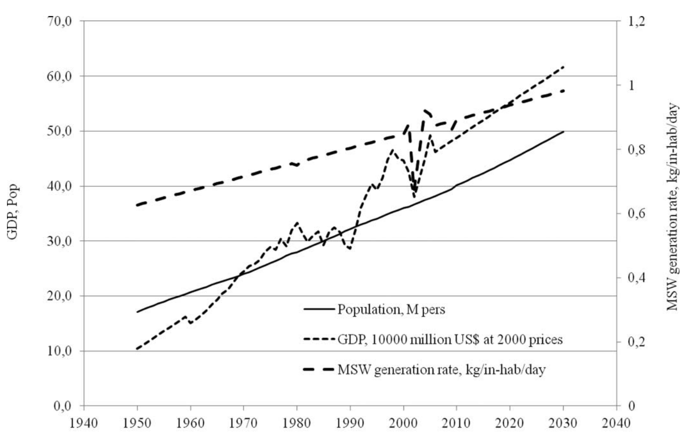

Figure 1. Trend of solid waste generation rate for the period 1950–2030 and its relationship with population growth and GDP.

Table 1. Waste composition and methane generation rate

Fraction	%	DOCi[a]	k[a]
Paper/cardboard	17.3	0.40	0.06
Textiles	2.3	0.24	0.06
Food waste	47.4	0.15	0.185
Wood	2.0	0.43	0.03
Garden waste	0.0	0.20	0.1
Diapers	4.5	0.24	0.1
Plastic	13.5		
Glass	6.0		
Metals	3.15		
Other	6.8		

Note: [a]IPCC Guidelines (2006).

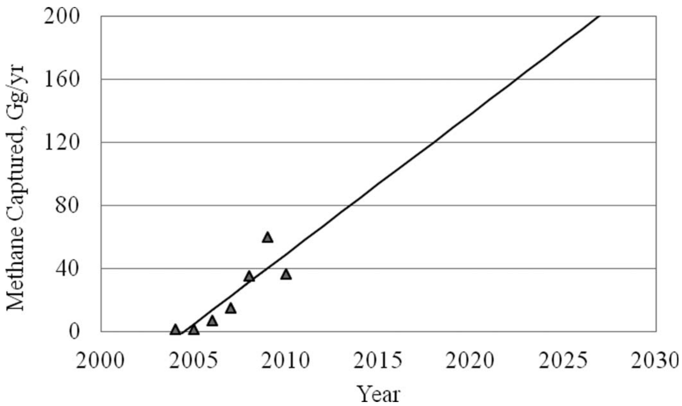

Figure 2. Trend of methane captured from real data (2004–2010) and projections to 2030.

Domestic wastewater category

Methane emissions for this category in the inventory year were estimated applying Tier 2 of IPCC Guidelines (2006) according to the following equation:

$$CH_4\,Emissions = \left[\sum_{i,j}(U_i * T_{j,i} * EF_j)\right] * (TOW - S) - R \quad (4)$$

where U is the fraction of population in income group i in inventory year (Table 6.5, 2006 IPCC Guidelines), with official data reported in National Census used; $T_{i,j}$ is the degree of utilization of treatment/discharge pathway or system j, for each income group fraction i in inventory year, with data from Table 6.5, 2006 IPCC Guidelines and National Census information, used; I represents the income group: rural, urban high income, urban low income, where data from National Census 1990, 2001, and 2010 were used; and j represents each treatment/discharge pathway or system according to official data published in the National Census 2001 and 2010 with projections downward (1990) and upward (2030) from linear regressions. In addition, EF_j is the emission factor, kg CH_4/kg biological oxygen demand (BOD) calculated as:

$$EF_j = Bo \times MCF_j \quad (5)$$

where *Bo* is the default maximum methane-producing capacity, assumed as 0.6 kg CH_4/kg BOD (2006 IPCC Guidelines), and *MCF* is the methane correction factor; the following default values suggested in 2006 IPCC Guidelines (Table 6.3, Chapter 6, Volume 5) were applied: for public network *aerobic treatment plant not well managed, overloaded* (0.3), *septic system* with half of BOD settling in anaerobic tanks (0.5), *latrine wet climate* (0.7), and *untreated system flowing sewer* (0). In addition, TOW is the total organics in wastewater in inventory year, kg BOD/yr, as:

$$TOW = P \times BOD \times 0.001 \times 365 \quad (6)$$

where P is the population in the year of inventory (official data from National Census were used) and BOD is the biologic oxygen demand per capita in g/pers/yr (the default value 14.6 suggested in IPCC Guidelines [2006] was used). Further, S is the organic component removed as sludge in inventory year, kg BOD/yr), and r is the amount of methane recovered in the year of inventory, kg CH_4/yr.

Nitrous oxide emissions (kg N_2O/yr) were calculated as:

$$N_2O\ emissions = N_{EFFLUENT} \times EF_{EFFLUENT} \times 44/28 \quad (7)$$

where $EF_{EFFLUENT}$ is the emission factor for N_2O emissions from discharged wastewater, kg N_2O-N/kg N (the default value 0.005 suggested in the 2006 IPCC Guidelines was applied), and $N_{EFFLUENT}$ is nitrogen in the effluent discharge to aquatic environment, kg N/yr, calculated as

$$N_{EFLLUENT} = (P \times protein \times F_{NONCOM} \times F_{INDCOM}) - N_{SLUDGE} \quad (8)$$

where P is human population (official data from National Census), *protein* is the annual per capita consumption, kg/person/yr (the value reported in SNC [2005] of 34.1, obtained from FAO [2004], was applied), $F_{NON\ COM}$ is the factor for nonconsumed protein added to the wastewater (the default value 1.1 suggested in IPCC Guidelines [2006] for countries without garbage disposal was applied), $F_{IND\ COM}$ is the factor of industrial and commercial protein co-discharged into the sewer system (the default value 1.25 suggested in IPCC Guidelines [2006] was used), and N_{SLUDGE} is the nitrogen removed in sludge, kg N/yr (a default value of zero was considered).

Industrial wastewater category

Methane emissions from on-site industrial wastewater treatment were calculated. Methane potential was based on the degradable organic matter and the trend to treat it in anaerobic systems. The evaluated sources of methane emissions from industrial wastewater were slaughterhouse, dairy, swine, sugar, citric, milk, and wine industries. Methane emissions were evaluated in a BAU scenario represented by the absence of wastewater treatment and its discharge to river as the usual practice, and in a mitigation scenario considering the implementation of anaerobic digestion as the technology for wastewater treatment and the capture of methane.

Methane emissions from industrial wastewater were estimated based on the Tier 2 of IPCC Guidelines (2006) with:

$$CH_4\,Emissions = \sum_i [(TOW_i - S_i)EF_i - R_i] \quad (9)$$

where TOW_i is the total organically degradable material in wastewater from industry i, kg COD/yr, calculated as

$$TOW_i = P_i * W_i * COD_i \quad (10)$$

where P_i is the total industrial product for industrial sector i, t/yr, W_i is the wastewater generated, m^3/t product, COD is the chemical oxygen demand, kg COD/m^3 (these three parameters were obtained from national statistics and previous related works: Santalla et al., 2008; Galotti and Santalla, 2009; Córdoba et al, 2011; Capittini and Santalla, 2011; Santalla and Córdoba, 2012);

S_i is the organic component removed as sludge in inventory year, kg COD/yr; and EF_i is the emission factor for industry i for treatment/discharge system used in inventory year, kg CH_4/kg COD, calculated as:

$$EF_i = Bo \times MCF_j \tag{11}$$

where Bo is the maximum methane producing capacity, kg CH_4/kg COD (the default value 0.25 was used [IPCC Guidelines, 2006]) and MCF is the methane correction factor, fraction—for the BAU scenario a value of 0.8 was applied, corresponding to *anaerobic deep lagoon* (Table 6.8, Chapter 6, IPCC Guidelines, 2006). This value was assumed according to results of a previous work (Galotti and Santalla, 2009), which described the current situation related to industrial wastewater management in Argentina. R_i is the amount of recovered methane in the year of inventory, kg CH4/yr; 0 and 80% of the generated methane was asumed in BAU and mitigation scenarios respectively. No sludge generation ($S_i = 0$) was considered.

The loading of the data in the software was carried out for each year of inventory and for each industrial sector, with their corresponding parameters and emission factors selected in such manner that for each inventory year the whole of methane emissions from all the industrial sectors evaluated can be obtained. Thus, each time a new field (industrial sector) has to be added, it can be incorporated into the database, recalculating the time series to achieve consistency.

Results and Conclusions

Methane emissions from solid waste disposal category

The database for methane emissions in solid waste disposal was developed setting the approach *waste by composition* and activity data from National Statistics (Tier 2) and the values for the degradable organic carbon and methane generation rate for each fraction as detailed in Table 1. Figure 3 shows the evolution of the methane emissions (in Gg CO_2e) of solid waste disposal (black bars) from the initial inventory year (1950) to 2030 projected in the BAU scenario. Methane emission will reach 9,622 Gg CO_2e in 2030, increasing 73% over the values obtained for 2000, the year of the last inventory. In a mitigation scenario, represented by the capture of methane emissions from landfills based on the actual trend, a decrease of 50% from the same year of the BAU scenario would be attained (gray bars, same figure). Net methane emissions (black line) show a deflection point around year 2005 (started with the implementation of the first CDM projects), followed by some variations during the period 2007–2010 that account for the actual values of the measured methane captured (as shown in Figure 2). Methane emissions per capita (dotted line) showed an increasing trend that follows the methane emissions varying from 13 (1950) to 192 (2030) Gg CO_2e/cap (Figure 3).

There are two areas of uncertainty in the estimation of methane emissions from solid waste disposal sites: the uncertainty attributable to the method, and the uncertainty attributable to the data (activity data and parameters). In order to evaluate the error due to the model, a sensitivity analysis was performed varying the assumed k-values (Table 1) within the ranges suggested in 2006 IPCC Guidelines (Table 3.3, Chapter 3, Vol. 5). To evaluate the uncertainty due to the data, the activity data and the fraction of degradable organic carbon that decomposes (DOC_F) were sensitized based on the estimated uncertainties in the FOD method. It is well known that Argentina has not developed a national registry system to elaborate periodic GHG inventories; therefore, there is a high uncertainty in activity data and also in some parameters associated with waste composition. While there is available updated technical information on waste generation rate and composition produced in highly concentrated regions, such as the Buenos Aires Metropolitan Area, Córdoba, and Santa Fe provinces, there is a large shortcoming in terms of information from the rest of the country. The sensitivity analysis indicated that the highest differences in methane emissions were around 20% (Figure 4) and were found when the fraction of degradable organic carbon that decomposes (DOC_F)

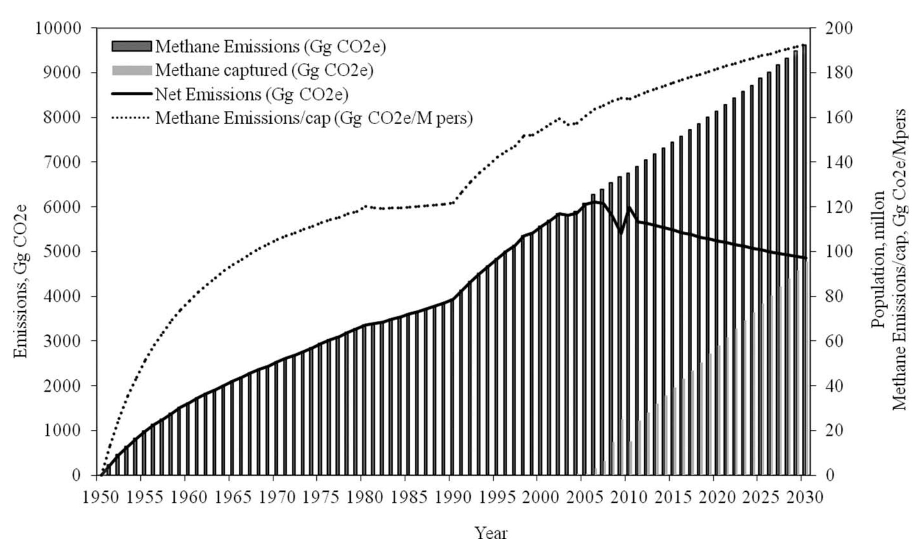

Figure 3. Evolution of methane emissions (Gg CO_2e) in solid waste disposal in a BAU scenario and a mitigation scenario and methane emissions per capita.

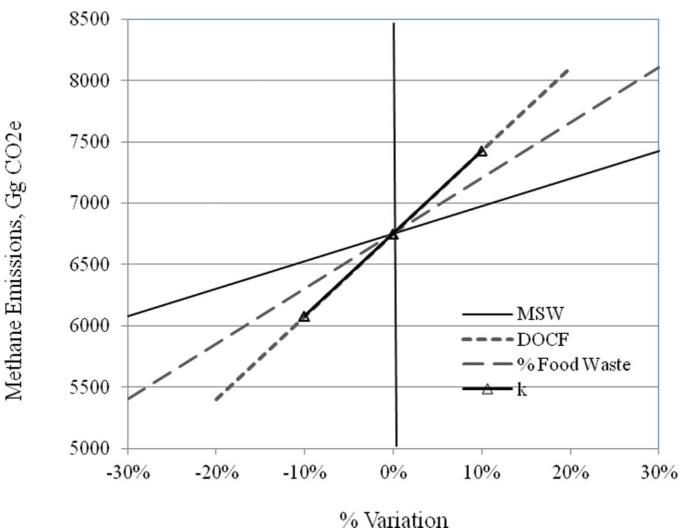

Figure 4. Sensitivity analysis to evaluate the error from method and from data of methane emissions estimation in solid waste disposal. (Color figure available online.)

varied by ±20% and when methane generation rate (*k*) varied in the range established in the IPCC Guidelines (2006), close to 10%.

The analysis of the behavior of emissions in relation to country economic indicators such as GDP showed that methane emissions per capita strongly increased with methane emissions per GDP (Figure 5). This can be explained by a higher consumption per capita and in some extent to a decrease in the efficiency of goods and service production system. The peaks observed in the years 1990 and 2002 correspond to the severe national economical crisis that occurred in Argentina during these years. The mitigation scenario shows the effect of the implementation of a mitigation policy in the waste sector reaching a progressive decrease in methane emissions, from 27% in 2015, and 36% in 2020, to 50% in 2030 in relation to the BAU scenario. Figure 5 reflects a mitigation scenario that should be achieved considering the methane capture in landfill only, without evaluating any other technology such as composting,

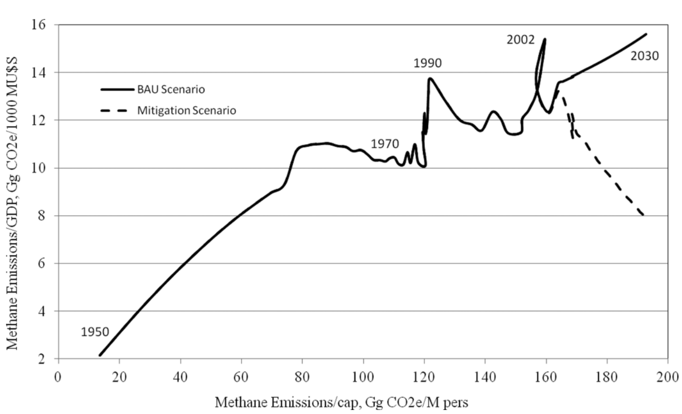

Figure 5. Evolution of methane emissions from solid waste disposal according to population and GDP in BAU and mitigation scenarios.

recycling of solid waste, or considering the energy use (electricity or thermal) and the corresponding fossil fuel displacement. In terms of mitigation potential in the waste sector, from all the identified MSW disposal sites of Argentina, at least 20 of them are likely to capture landfill gas (LFG) for use as thermal or electrical energy, many of them linked to the urban cities with more than 100,000 inhabitants. The technology for the capture and use of LFG is commercially available and there is even the ability to develop local suppliers. As the use of LFG is still not a common practice, electricity production is further behind. One of the main barriers is the prevailing fossil fuel energy matrix, in spite of an official initiative emerged in 2006 through the National Law 26190 promotes the production of electricity based on renewable resources. This regulatory framework has introduced an incentive for the production of electricity from LFG, although the minimum power capacity required of 1 MW offers only to the larger landfills the possibility of selling the power generated to the national grid.

Domestic wastewater

Methane and nitrous oxide emissions for the time series 1990–2030 are shown in Figure 6. Methane emissions will increase 74.4% from 2000 to 2030, reaching 3,844 Gg CO_2e. The slope change in the trend of methane emissions observed from 2011 is explained by changes in the degree of utilization the type of treatment or discharge obtained from the national census, which revealed an increase of 10% the fraction of population with centralized treated system (aerobic not well managed, overload), 6% increase in the use of latrines, and 18% decrease of untreated systems.

As almost 40% of the population is concentrated in the Buenos Aires Metropolitan Area, most domestic wastewater is concentrated in this area. The common practice for the sanitation of domestic wastewater is the centralized wastewater treatment plants (WWTPs); therefore, there is a high potential of mitigation of methane emissions in the sludge treatment that usually these plants dispose of.

Nitrous oxide emissions from domestic wastewater resulted in 659 Gg CO_2e in year 2000, 46% lower than those reported in the SNC (2005), mainly due to the default value adopted for the emission factor for N_2O emissions from discharged of wastewater used ($EF_{EFFLUENT}$), which is half of the value suggested in the 1996 IPCC Guidelines.

Industrial wastewater category

Methane emissions from this category are shown in Figure 6 for the industrial sectors evaluated. The variation observed in the 2000–2004 series was explained by the economic crisis of 2001, while the observed decrease in 2010 was due to the lower levels of production in cattle (Córdoba et al., 2011) slaughterhouse, sugar, and citrus industries (Galotti and Santalla, 2009). Projected emissions to 2030 resulted as 58.5% higher than those in 2000, reaching 3,887 Gg CO_2e. The higher source of methane emissions resulted from the manure management in swine and dairy (70%),

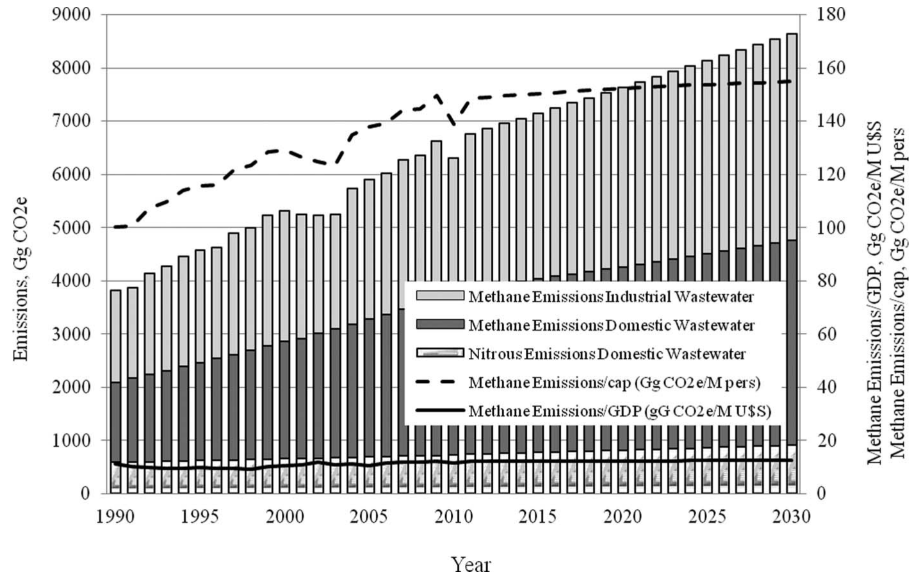

Figure 6. Evolution of methane and nitrous emissions (Gg CO_2e) in domestic and industrial wastewater categories. Total methane emissions from these sectors and their variation with population and GDP.

followed by slaughterhouses (16%) and the dairy industry (12%). A mitigation scenario for the sector reported in a previous work (Santalla and Córdoba, 2012) indicates that anaerobic digestion technology could mitigate around 80% of the methane emissions of the sector, approximately 2,016 Gg CO_2e annually, which could provide approximately 4 TJ per year of thermal energy. During recent years, and particularly in the context of the CDM incentive, some anaerobic lagoons and reactors have been installed in Argentina to capture biogas and use it as a source of thermal energy for consumption in the same processes, usually to replace fossil fuels. In spite of anaerobic digestion not being a common practice and several identified barriers that still need to be overcome (Santalla and Córdoba, 2012), the mitigation potential has a surplus on GHG reduction, as methane is captured and fossil fuels are displaced, reducing carbon dioxide emissions.

A comparison between calculated GHG emissions in waste sector in Argentina based on 2006 IPCC Guidelines and previous inventories is shown in Table 2. GHG emissions for the period 2005–2030 were compared with a non-official study of prospective of GHG emissions (Bariloche Foundation, 2008).

Table 2. Comparative methane emissions (Gg CH_4)

Category/inventory year		Solid waste disposal	Domestic wastewater	Industrial wastewater
1990	a	208	147	55
	c	187	72	82
1994	a	238	154	55
	c	223	84	98
1997	a	261	159	90
	c	245	94	108
2000	a	357	164	101
	c	265	105	117
2005	b	611	171	105
	c	290	123	125
2010	b	867	223	121
	c	322	144	122
2020	b	1486	247	154
	c	387	164	160
2030	b	2214	272	175
	c	458	183	185

Note: a, 1990–2000 Reported data from SNC (2005); b, 2005–2030 reported data from the non official study (Bariloche Foundation, 2008); c, present study.

The results indicated that methane emissions from solid waste disposal estimated by the application of the FOD model resulted in 12% (average) lower methane emissions than reported in the SNC (2005) and 67% (average) lower than values reported in the non official study (Bariloche Foundation, 2008). The main sources of difference were the applied models (and the emission factors associated) and the activity data. Methane emissions from disposal sites were calculated according three different models: the decomposition method and the default method used in the SNC (2005) based on the 1996 IPCC Guidelines; the LandGEM gas emissions model (U.S. EPA, 2005) used in the non official study (Bariloche Foundation, 2008); and the FOD model based on Tier 2 of the 2006 IPCC Guidelines applied in the present study. In terms of the activity data, the main source of difference was the amount of MSW to be deposited in landfills in the period 2010–2030 based on the generation rate calculated on the GDP growth. The nonofficial study (Bariloche Foundation, 2008) projected an MSW increase 33% higher than the present study, achieving in 2030 a generation rate of 1.3 kg/day/inhabitant, compared to 0.98 kg/day/inhabitant in the present study. This last value agrees with the projection of MSW generation rate reported by Gonzalez (2010) in a study on the current Argentine situation and future alternatives for MSW, with trends that match for the years 2005, 2010, and 2015 with the present study. Despite these differences, GHG emissions in the mitigation scenario had similar results, projecting 50% (present work) and 44.3% (Bariloche Foundation, 2008) emission reductions.

For domestic wastewater, methane emissions calculated based on 2006 IPCC Guidelines resulted in 43 and 32% lower values than values reported in SNC (2005) and the nonofficial study (Bariloche Foundation, 2008) respectively. The main sources of difference were the default values applied for the methane correction factors and the fraction of wastewater treated in the different wastewater handling system.

Regarding industrial wastewater, the estimates obtained in this work for the 1990–2030 series resulted as 23 and 12% higher than those reported in SNC (2005) and the nonofficial study (Bariloche Foundation 2008), respectively. The main source of difference was the fraction of wastewater treated in anaerobic conditions applied in the BAU, being only 10% in SNC (2005) and 80% in the present work.

Concerning the use of the ad hoc software developed by IPCC for the application of 2006 IPCC Guidelines, this was shown to be a useful tool to develop new GHG national inventories attainable when updated information or new parameters have to be included for recalculation purposes in order to achieve consistency of the inventories. Some issues related to the interaction between multiple users and the management of the database nationwide are yet to be proven in Argentina.

The 10% difference in methane emissions attributable to the activity data uncertainty should not be underestimated, as this variation can be considerable when waste or waste composition changes significantly over time and regions of a country, as happens in Argentina.

This work represents the first and preliminary application of the 2006 IPCC Guidelines in a specific sector of a GHG inventory. The results indicate the importance of developing a national system that systematically produces high-quality data in order to ensure transparency, consistency, comparability, completeness, and accuracy in the preparation of the GHG inventory as defined in the respective guidelines. The national system should be designed in a way that guarantees consistent methodology for collecting activity data, selecting of methods and emission factors, and carrying out procedures for the verification of the inventory data at the national level.

References

Bariloche Foundation. 2008. Argentina: Diagnóstico, Prospectivas y Lineamientos para definir Estrategias posibles ante el Cambio Climático. Producto 2: "Proyecciones anuales de las emisiones de GEIs, destacando en el análisis los años 2010, 2020 y 2030" Escenario Tendencial (BAU). Producto 3: "Proyecciones anuales de las emisiones de GEIs" Escenario de Mitigación. Proyecto realizado para la Comercialización de Energía del MERCOSUR S.A. (CEMSA). Buenos Aires, Argentina.

Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, and T. Zhang. 2007. Waste management. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. New York, NY: Cambridge University Press, pp. 585–618.

Capittini, A., and E. Santalla. 2011. Efluentes de la Industria Láctea: amenaza u oportunidad? In *Proceedings II Congreso Internacional de Ambiente y Energías Renovables*, Córdoba (Argentina), 9–11 November 2011, 345–54.

Córdoba V., G. Blanco, D. Crozza, and E. Santalla. 2011. Emisiones de Metano en el Sector Ganadero Argentino. In *Proceedings II Congreso Internacional de Ambiente y Energías Renovables*, Córdoba, Argentina, 9–11 November 2011, 240–51.

ENGIRSU. 2005. Estrategia Nacional para la Gestión de los Residuos Sólidos. www.ambiente.gov.ar

FAO. 2004. Statistical Database. United Nations Food and Agricultural Organization. http://faostat.fao.org.

Galotti, P., and E. Santalla. 2009. Estimación del Potencial Energético de los Efluentes Industriales. *Av. Energías Renov. Medio Ambiente* 13: 187–94.

González, G. L. 2010. Residuos Sólidos Urbanos Argentina. Tratamiento y Disposición Final. Situación actualy alternativas futuras. Cámara Argentina de la Construcción. Área de Pensamiento Estratégico. Diciembre.

Instituto Nacional de Estadísticas y Censos, INDEC. 2004. *Estimaciones y Proyecciones de Población. Total del país 1950–2015*. Serie Análisis Demográfico number 3.

Intergovernmental Panel on Climate Change. 2002. National Greenhouse Gas Inventories Programme. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventory. http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm

Intergovernmental Panel on Climate Change 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the National Greenhouse Gas Inventories Programme, eds. H.S. Eggleston, L. Buendía, K. Miwa, T. Ngara, and K. Tanabe. Tokyo, Japan: IGES.

Santalla, E., and V. Córdoba. 2012. Tecnologías para el aprovechamiento energético de residuos urbanos y de los sectores agrícola, ganadero y agroindustrial. Proyecto de Evaluación de Necesidades Tecnológicas para la Mitigación y Adaptación al Cambio Climático en la Argentina. Ministerio de Ciencia, Tecnología e Innovación Productiva. PNUMA-UNEP Risoe Centre. Contrato de Consultoría 1215227-03.

Santalla, E., V. Córdoba, and D. Crozza. 2008. Estudio de Performance Ambiental, Contrato entre la Universidad Nacional del Centro de la Provincia de Buenos Aires UNCPBA y el Banco Mundial (Contrato N° 7145486). Evaluación, diagnóstico y propuestas de acción para la mejora de las problemáticas ambientales y mitigación de gases de efecto invernadero vinculadas a la producción porcina, bovina (feedlots y tambos) y avícola. (Crozza D., Córdoba V. y Santalla E.). 209 pág. Informe para el Banco Mundial BIRF a través del Fondo Argentino de Carbono. Contrato UNCPBA–Banco Mundial N° 7145486 http://www.ambiente.gov.ar/?Idarticulo=6878

Secretaría de Ambiente y Desarrollo Sostenible de la Nación (SAyDS). 2010. *Sistema de Indicadores de Desarrollo Sostenible*. 5th ed. http://www.ambiente.gov.ar/archivos/web/Indicadores/file/publicaciones/2010_indicadores.pdf

Second National Communication of the Government of Argentina to the UNFCCC, 2005. http://www.ambiente.gov.ar/?idarticulo=1124

USEPA. 2005. *Landfill Gas Emission Model (LandGEM), Version 3.02, Userás Guide*. http://www.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf

About the Authors

Estela Santalla, MSc., is a titular professor and researcher at the College of Engineering, Chemical Engineering Department, in Olavarría, Argentina.

Verónica Córdoba is a chemical engineer, Ph.D. student, and researcher at the Bioenergy Lab at the College of Engineering, Chemical Engineering Deparatment, in Olavarría, Argentina.

Gabriel Blanco, MSc., is a titular professor and researcher at the College of Engineering, Mechanic Engineering Department, in Olavarría, Argentina.