COMPARING LCA AND CDM METHODS – TWO WAYS TO CALCULATE GREENHOUSE GAS EMISSION REDUCTION DUE TO ORGANIC WASTE TREATMENT

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ABSTRACT

The research study presented in this paper compares three treatment scenarios for organic municipal waste in the context of Cochabamba, Bolivia and quantifies greenhouse gas emissions using two methods. The options are: 1) disposal of organic waste at a landfill; 2) treatment by anaerobic digestion; 3) treatment by composting. Two different approaches to quantify greenhouse gas emissions of the waste treatment scenarios were applied: a) the methodology used in CDM projects to calculate Certified Emission Reductions (CERs); and b) the Life Cycle Analysis technique used in research and academia. Both methods show that treatment of organic waste has a large emission reduction potential when compared to landfill disposal. CDM methodology underestimates the effective emissions. Additionally, for composting the default value only seems to be accurate when good operational practices are guaranteed. For the case of Cochabamba the unfavourable climatic conditions result in a rather low potential to obtain certified emission reductions.

INTRODUCTION

In many developing countries, methane (CH_4) emissions from waste management and specifically from landfills is the largest anthropogenic source of atmospheric CH_4 (Spokas et al., 2006). These emissions occur when solid waste containing organic matter is disposed at a landfill. Under anaerobic conditions the biodegradable fraction undergoes microbial decomposition and forms landfill gas mainly containing CH_4 and CO_2 (Obersteiner et al., 2007). With increasing thickness of the waste layer at the dump site the potential for anaerobic decomposition increases and thereby also the potential for CH_4 generation. In uncontrolled dump sites, landfill gas is neither collected or flared and therefore released in an uncontrolled way into the atmosphere. Matthews and Themelis (2007) estimate that landfills contribute between 5-10% of global methane emissions or about 10% of the anthropogenic fraction. This indicates that with improved waste management and appropriate waste treatment technologies there is a large potential to contribute to a reduction of global greenhouse gas emissions.

In recent decades municipal solid waste management has become a major priority for municipalities and local governments and one of their major challenges (Zurbrügg, 2012). Especially in low- and mid-income countries where waste collection service coverage is low and appropriate treatment is lacking, this leads to water, land and air pollution, putting people's health and the environment at risk (CWG, 2008). Current trends of increasing urbanization and economic development in many developing countries suggest that the problem will intensify as more waste is generated and with increasing coverage also more waste is transported and landfilled. Furthermore the trend towards controlled landfilling may also results in higher rates of CH_4 generation and emissions than the previous open-dumping and burning practice. Therefore a close look must be directed towards alternative treatment for the organic fraction of waste while focusing on a quantification of potential greenhouse gas emissions reduction as compared to landfilling. Comparison of different treatment options for organic waste and their respective CH_4 emissions can be a critical factor influencing decision making for the implementation of project activities in waste management.

In 1997 the Kyoto Protocol was developed with the goal to reduce greenhouse gas emissions until the year 2012. This legally binds countries that ratified the Protocol to reduce their greenhouse gas emissions by 5.2% relative to the year 1990 (UNFCCC, 2011). To support countries in limiting or reducing their greenhouse gas emissions and to encourage the private sector and developing countries to contribute, the Kyoto Protocol introduced the Clean Development Mechanism (CDM) (UNFCCC, 2010a). With the support of the Clean Development Mechanism developing countries can obtain finances to support emission reduction projects. through the sale of Certified Emission Reductions (CERs) These CERs, each equivalent to one tone of CO_2, can be traded and used by industrialized countries to meet a part of their emission reduction targets (UNFCCC, 2010a). To estimate CO_2 reduction potential, the United Nations Framework Convention on Climate Change (UNFCCC) provides approved methodologies and guidelines. However, these methodologies only consider greenhouse gas emissions and neglect any further environmental impact such as consumption of scarce resources or emission of pollutants others than greenhouse gases. On the other hand Life Cycle Assessment (LCA) offers the possibility to assess the entity of the environmental impact of a process or a product and therefore allows to take further criteria other than climate change into account.

The research study presented in this paper compares three different treatment scenarios for organic municipal waste in the context of Cochabamba, Bolivia and quantifies their greenhouse gas emissions using two different methodologies. The first is the conventionally used and approved methodologies used in CDM projects to calculate the expected Certified Emission Reductions (CERs). The other method is the Life Cycle Analysis technique, most frequently used in research and academia. The three waste treatment options compared are: 1) the disposal of organic waste at a landfill (which is considered the baseline); 2) the treatment by anaerobic digestion; 3) the treatment by composting. The two organic waste recycling options link to an ongoing technical cooperation project called *"Ecovecindarios"* led by the Swiss Foundation for Technical Cooperation (Swisscontact) in Cochabamba, Bolivia. As the project would like to benefit from financial support through the Clean Development Mechanism a detailed calculation of the possible greenhouse gas emission reductions for the two options is required.

Solid Waste Management in Cochabamba, Bolivia

Bolivia is a landlocked country in Central South America, with a surface area of 1'098'581 km^2 and a population of 10'118'683 inhabitants (CIA, 2011). The climate in Bolivia is dominated by the country's largely variable altitude which ranges from 130 m.a.s.l. in the lowlands of the Amazon Basin up to 6'542 m.a.s.l.in the Andes mountain range. Despite its large natural resources, Bolivia is one of the poorest and least developed countries in Latin America. Cochabamba is the fourth largest city of Bolivia with a population of 625'429 inhabitants at an altitude of 2'558 m.a.s.l. with a sunny and moderate climate and with an average temperature of 17.6 °C. The climate is relatively dry, except during the rainy season between November and March where heavy rainfall events occur (INE, 2011). Collection and disposal of municipal waste in Cochabamba lays in the responsibility of the municipal services "Empresa Municipal de Servicios de Aseo (EMSA)". Household waste is collected regularly on defined routes in the different neighborhoods of the city and then transported to the landfill K'ara K'ara south of the city. During the past years, waste disposal at the landfill has led to social conflicts given its insufficient management and the resulting health and environmental threats. Solutions are sought to reduce the amount of waste transported to K'ara K'ara for final disposal. Cochabamba has a waste production of 0.51 kg per inhabitant and day which amounts to about 319 tons of solid waste per day. The share of organic waste is 61% (66% considering the whole district) however, experiences of Swisscontact (2010) show that recovery of only 42% (134 t/day) of the organic fraction is feasible.

METHODS AND MATERIALS

This study compares a baseline of organic waste disposal at a landfill (scenario 0) with two organic waste treatment options, anaerobic digestion (AD) (scenario 1) and composting (scenario 2) Two methods are used to assess greenhouse gas emissions of the three scenarios. The first method is the one typically used in CDM projects which is approved by UNFCCC to calculate the expected Certified Emission Reductions (CERs). The second method is the Life Cycle Analysis technique.

UNFCCC and CDM Methods

The methodologies used from UNFCCC include the simplified methodologies for small scale projects which must meet the following criteria: for type I projects (Renewable Energy) the energy production potential of 15 MW shall not be exceeded and for type III projects (Waste Management) the emission reduction cannot go beyond the limit of 60’000 tons of CO_2 equivalent (CO_2e) per year. For project activities, where the emission reduction increases during the crediting period the project activities must remain under the limits of small scale projects every year during the crediting period (UNFCCC, 2011c). For the scenarios calculated in this study these conditions are met. The methods and tools used are as follows (more information on the methods is available at the UNFCCC web site).

- III.AO: Methane recovery through controlled anaerobic digestion
- III.F: Avoidance of methane emission through composting
- I.CT: Thermal energy production with or without electricity
- III.H: Methane recovery in wastewater treatment
- I.D: Grid connected renewable electricity generation
- Tool: methane emissions from disposal of waste at a solid waste disposal site
- Tool: project or leakage CO_2 emissions from fossil fuel consumption
- Tool: emission factor for an electricity system

The baseline scenario reflects all the emissions occurring without implementing any CDM project activity and is calculated with an equation (UNFCCC, 2010b) based on the First Order Decay Model (FOD). The results are in tons of CO_2 equivalents (tCO_2e) emitted. Projects such as composting or anaerobic digestion divert waste from disposal and therefor avoid this amount of CO_2e. Specific project emissions are then deducted to obtain the total emission reduction.

For composting and AD, project emissions comprise: a) emissions from incremental transport of waste (or co-substrate) in the year; b) emissions from incremental transport of compost (or digestate) in the year; c) emission from electricity or fossil fuel consumption for composting or AD in the year; d) methane emissions from composting or leakages from AD in the year; e) emission from treatment of leachate in the year.

If biogas from AD is used as a substitute for a fossil fuel energy source these additional emission reductions can be credited, whereby two options from combustion of biogas, generation of electricity or thermal energy generation, can be distinguished. In addition a calculation of the avoided emission of wastewater treatment were included as in the case of Bolivia co-substrate digestion from a slaughterhouse was envisaged.

Life Cycle Analysis Methods

In the Standard ISO 14040, the Life Cycle Assessment is defined as a methodology to assess the environmental aspects and significant environmental impacts related to a product or service. This service is defined in the "functional unit" and different processes providing the same service can be compared with regard to their environmental impact (Klöpffer and Grahl, 2009). The system boundary used is geographical site of the municipality of Cochabamba with its surrounding agricultural areas and the time frame is defined as 100 years, assuming that thereby in most of the long term emissions are included. Benefits to the environment by substituting goods that would have caused a certain environmental impact are also taken into account. These are: a) Renewable energy: as the produced biogas from anaerobic digestion can be used further as an energy source and substitutes energy from other sources; b) Organic fertilizer: as anaerobic digestion and composting produce an organic fertilizer that can be used on fields otherwise fertilized by inorganic fertilizers.

The overall environmental impact caused by emissions and resource consumption described in the inventory was assessed using the indicator IPCC 2007 GWP (for CO_2e emissions) and ReCiPe Mid/Endpoint method, version 1.05 (for environmental impact) (Forster et al., 2007; ReCiPe, 2011). This paper however only highlights the results concerning the CO2e emissions. A brief summary of the inventory for each option is described below. More details on inventories and ReCiPe results are described in Volkart (2011).

Inventory for Anaerobic Digestion: The infrastructure data is based on a fictional industrial biogas plant which includes a storage vessel, the main reactor and a gas storage reactor, a heat exchanger and a management building. The reactor is made out of steel and concrete and includes stirrers to ensure homogenization. Furthermore the system includes a heat exchanger to warm up the substrate before it is fed into the reactor. Additionally, a management and technology building is required, where offices, toilets, showers, as well as storages units are situated. The building is considered to be made of concrete, bricks and corrugated sheet metal (Hartmann, 2006). The inventory includes emissions and resource consumption from the construction and disposal of the plant. The operation of the biogas plant consumes energy mainly for pumping and stirring the substrate and to heat the substrate to operation temperature (Deublein and Steinhauser, 2011). The electric energy consumption is assumed to be covered by electricity from the national grid of Bolivia. In addition a calculation of the avoided emission of wastewater treatment were included as in the case of Bolivia co-substrate digestion from a slaughterhouse was envisaged. From the anaerobic digestion of organic waste, gaseous emission such as CH_4, N_2O and NH_3 occur and are considered in the inventory. Emissions occur mainly during the maturation process when fresh digestate is mixed with compost material and undergoes an aerobic process (Edelmann and Schleiss, 2001) but also during delivery, preparation and final solid matter separation of the substrate. Additionally methane may escape from leaks if the plant is not completely gastight (Gyalpo, 2010; UNFCCC, 2010c). This is assessed in a sensitivity analysis. The amount of produced biogas is calculated according to the composition of the organic waste in Cochabamba. For both uses, electricity and biogas, it is assumed that an equal energetic amount of either electricity from the grid or natural gas is substituted, providing credits for the avoided emissions from combustion of fossil fuel. With use of compost or digestate in agriculture, the effect of the introduced nutrients but also contaminants such as heavy metals are considered. To estimate the emissions from transportation, infrastructure of the trucks and the distance to the city market La Cancha (amount of combusted fuel) were calculated.

Inventory for Composting: The infrastructure consists of an open compost plant on concrete ground, including a leachate collection system. The area where the intensive composting process takes place under a roof and the maturation is considered to be under open sky. For the infrastructure of the compost plant all the emissions from the construction and disposal of the plant are taken into account (Edelmann and Schleiss, 2001). Energy is consumed from shredding and loading the waste, turning the windrows and maintaining the system for forced aeration. The electricity consumption is covered by electricity from the national grid while emissions from the fuel consumption are calculated considering the resource consumption as well as emissions from combustion. During composting some N_2O, NH_4, and CH_4 are emitted (Edelmann and Schleiss, 2001; Stucki, 2007) and are considered as emissions. The emissions from application of compost as well as emissions from transportation are assumed to be equal to the ones from the scenario of anaerobic digestion.

Inventory for Landfill: The inventory accounts for all emissions from the construction of a sanitary landfill including resource and energy consumption and emissions. The landfill is designed for the storage of 1.8 million m3 of waste and is assumed to be partly submerged below the existing surface and to rise above it after closure. The plant includes a leachate collection system as well as roads accessing the landfill (Doka, 2009). The waste disposed at the landfill causes gaseous emission, mainly consisting of CO_2 and CH_4. Biogenic CO_2 emissions are considered carbon-neutral however CH_4 emission and additional airborne pollutants are taken into consideration. Additionally, it is also considered that a fraction of the produced CH_4 is oxidized in the clay landfill cover and another part is flared. This is subtracted from the produced emissions. During operation of the landfill fuel is consumed by activities such as waste compaction, regular covering and maintenance of the leachate recovery system. All these activities are required because of the organic waste and are therefore all accounted towards the organic fraction. For transport of waste to the landfill, the trucks and fuel consumption are taken into account.

Data Collection

The calculations were done for project scenarios, in other words for a project which has not yet been implemented. Most site specific data was obtained from secondary sources relating to the current waste management and treatment experiences in Cochabamba. To complete the inventory for the three scenarios, different approaches for data collection were applied: Literature research was used to obtain information on the necessary material and energy flows of the waste treatment processes. Furthermore, different studies to assess the specific emissions of organic waste treatment were reviewed. During a field visit in Cochabamba, semi-structured interviews with stakeholders were conducted to obtain information about the current waste management as well as to assess the enabling environment for the implementation of the new project. Where applicable, data gaps were filled using default values suggested in the IPCC Guidelines for National Greenhouse Gas Inventories. Where available, processes from the Ecoinvent Database (Frischknecht and Rebitzer, 2005) were used either directly or then in a slightly modified manner.

RESULTS and DISCUSSION

LCA Results

Scenario 0: Considering the Global Warming Potential (GWP) assessed with the method IPCC 2007 GWP 100y the overall impact of landfill disposal is estimated to be a total of 868 $kgCO_2e$ per ton of organic waste landfilled. The contribution of CH_4 emissions account for 97% of the total GWP, transportation for 1.87% (16.2 $kgCO_2e$) and infrastructure for 0.79% (6.87 $kgCO_2e$) (Fig. 1).

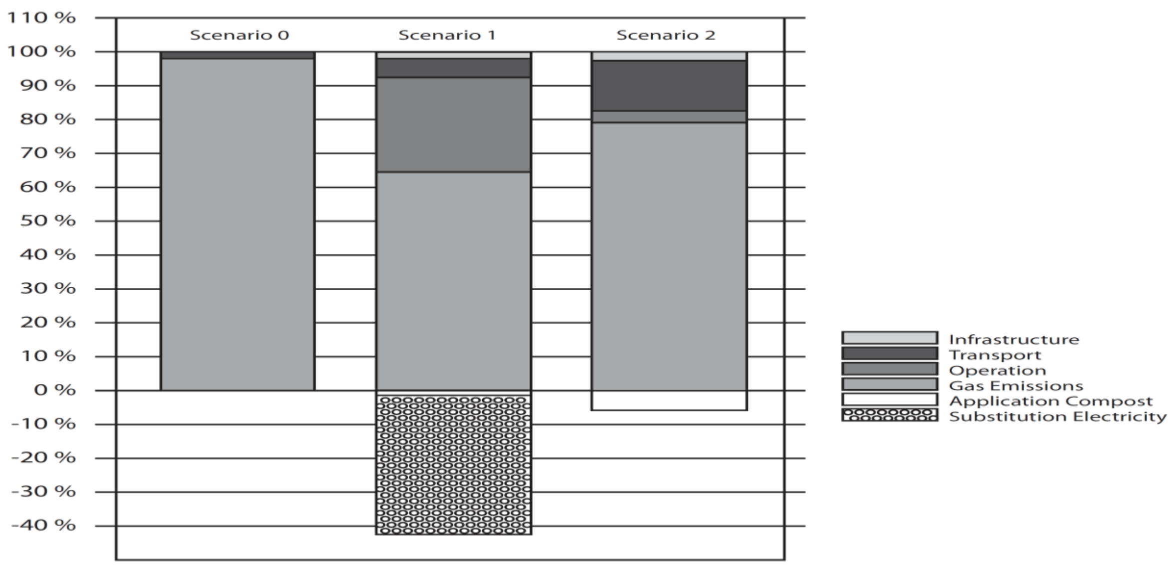

Figure 1: Percent of environmental impact by categories for the three scenarios (GWP IPCC 100y) (adapted after Volkart, 2011).

Scenario 1: The total emission from anaerobic digestion project activities (based on GWP) amount to 299.54 kgCO_2e per ton of organic waste treated. The largest share of emissions are caused by the operation of the plant (74.1 kgCO_2e) and the gaseous emissions of organic matter before, during (leakage), and after the biogas plant (192 kgCO_2e) (Fig.1). Except for the digestion of organic matter, in which case the total GWP is entirely caused by CH4 (151 kgCO_2e) and N2O (41 kgCO_2e), all other processes at the AD plant contribute almost exclusively by the emission of fossil fuel combustion. On the benefit side, the conversion of the gas to electricity and its use as a substitute to Bolivian electricity grid helps to avoid 125 kgCO_2e, while the application of compost causes a reduction of the overall emission by 6.54 kgCO_2e, mainly by avoided fossil fuel combustion. The net total emissions are therefore 168 kgCO_2e per ton of organic waste treated.

Scenario 2: For the compost scenario, total greenhouse gas emissions (GWP) account for 108 kgCO_2e. The largest impact is caused by gaseous emissions during the composting process with a contribution of 91 kgCO_2e. Of the 91 kgCO_2e, CH4 accounts for the largest share with 59.7 kgCO_2e while N2O contributes with 31.1 kgCO2e. Operation of the plant (4.18 kgCO_2e) and the infrastructure of the biogas plant (2.6 kgCO_2e) contribute only little to the total emissions (Fig.1). The emissions from transport of waste and the transport and application of compost as well as the benefits from compost application are equal as in the scenario of anaerobic digestion.

CDM Results

Scenario 0: Table 1 shows the total and yearly average emission reductions that could be achieved by avoiding waste disposal, calculated for different crediting periods and 1 t organic waste per year landfilled. The table also shows the variation in results depending on the climate zones, which are characterized by temperature and dryness (influencing the decay rates used).

Table 1: Total and yearly achievable emission reduction by avoiding landfill disposal, in kgCO_2e for 1 t organic waste per year for different climate characteristics (Volkart, 2011).

Crediting Period	Total				Yearly Average			
	≤20°C		>20°C		≤20°C		>20°C	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
7	993	1996	1281	2923	142	285	183	418
10	1859	3513	2359	4831	186	351	236	483
21	6609	10’543	7996	12’728	315	502	381	606

Scenario 1 and 2: The results for project emissions of anaerobic digestion and for the two different composting technologies are shown in Figure 2. The calculations indicate that the largest share of emissions is caused by on-site fuel and electricity consumption and CH_4 emissions from degradation of organic matter or from leakage of the biogas plant. The CH4 emissions from composting account for 84.00 kgCO_2e/t and are slightly higher than the estimated physical leakage of 69.73 kgCO_2e/t from anaerobic digestion.

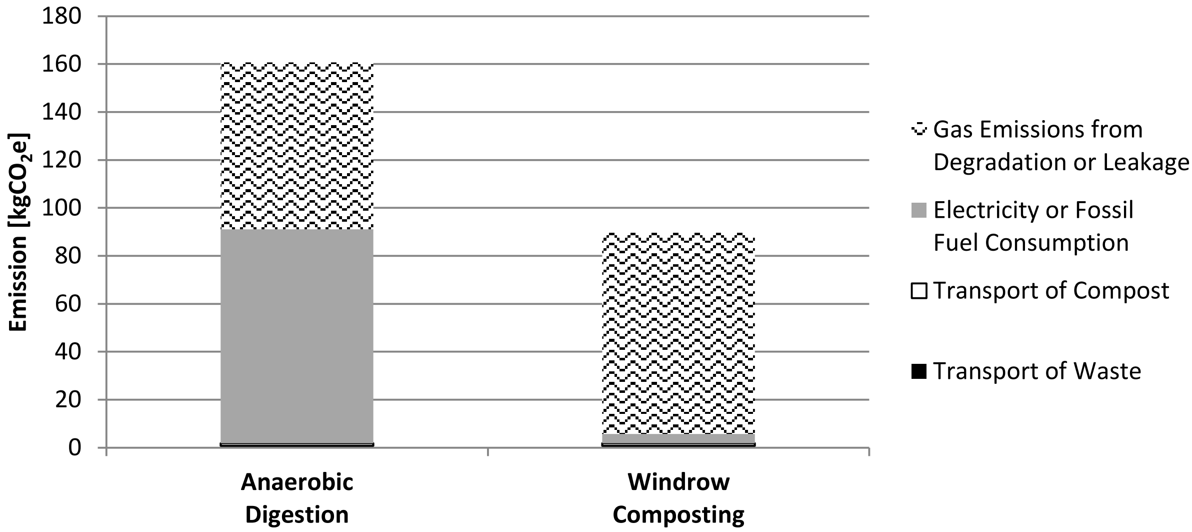

Figure 2: Project emission by categories for anaerobic composting (scenario 1) and windrow composting (scenario 2) in kgCO_2e per ton of organic waste and year (Volkart, 2011).

The biogas plant accounts for the emission of 89.24 kgCO_2e/t from power consumption whereas the emissions from energy consumption from the windrow compost facilities are much lower. Besides the avoidable emissions of landfill disposal, anaerobic digestion will also avoid emission through substitution of energy as well as avoiding emissions from wastewater treatment (as the plant uses wastewater as co-substrate) . When using the gas to produce electricity 133.45 kgCO_2e/t are avoided. With gas use as thermal source the emission reductions are slightly lower (119.35 kgCO_2e/t). Avoiding emissions from wastewater treatment accounts for 78.87 kgCO_2e/t.

Sensitivity Analysis

With the LCA approach various uncertainties were assumed and the respective sensitivities calculated. For landfill disposal calculations were also conducted for an oxidation rate in the soil cover of zero (instead of 25%). This causes an increase of 44.01% considering GWP. Similar results were calculated for landfill gas flaring, where a non-functional landfill gas capture and flaring system would increase GWP by 34.79%.

High uncertainties exist in the available data considering the greenhouse gas emissions during the decomposition of organic waste by anaerobic digestion or composting. The total GWP from anaerobic digestion ranges from <1% up to 137% of the default scenario, depending on the factors used for emissions caused during the degradation processes of waste or digestate before and after the anaerobic treatment. If additionally also different leakage factors are considered, the GWP may vary up to 274% of the default result. The compost plant shows a smaller variability ranging from 48% to 192% of the calculated default result of GWP. Using the default emission factor from IPCC (2006) leads to the highest value. The influence of other uncertainties were also calculated in Volkart (2011) - such as: i) choice of composting technology (forced aeration or closed reactor composting); ii) variation of emissions from the application of compost/biodigest; iii) variation of the use of gas; iv) changing of transportation system - but are all not further reported in this paper.

COMPARISON OF RESULTS AND CONCLUSIONS

In comparison with the results from LCA, the emission reductions quantified with the approved CDM methodologies for composting and anaerobic digestion seem to underestimate the real emission reduction potential of the project activities. Already the calculations of baseline emissions differ. However these results have to be interpreted with caution as CDM and LCA use different approaches. While LCA assesses the emissions of a certain amount (1 t) of organic waste over a period of 100 years, the CDM Baseline Methodology calculates the emissions over a certain time frame (usually per year) based on the crediting period (7, 10 or 21 years). For short crediting periods the potential to avoid emissions is smaller and the difference to the result from LCA increases. The impact of climate is also reflected in the register of already validated composting projects. All of the 41 validated small scale projects introducing composting of organic waste were carried out in rather tropical climates of Malaysia, Indonesia, India and Brazil (UNFCCC, 2011). Considering the climate in Cochabamba, the decay rates to be used would be rather low, hence only a small share of waste would be degraded after the end of the crediting period resulting in low amount of emission reduction credits.

Another difference is in the conversion factor of CH_4 to CO_2e. The indicator IPCC 2007 GWP 100y - as used in the LCA - considers the factor for CH_4 of 25 CO_2e (Forster et al., 2007) based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. However, the Kyoto Protocol was signed in 1997 while the Second Assessment Report of the Intergovernmental Panel on Climate Change was still state of the art. This report suggested a factor for CH_4 of 21 CO_2e (Houghton et al., 1995). Hence the result from CH_4 emissions assessed with the CDM methodology will always be less than when using IPCC 2007 GWP 100y.

Emissions caused by the application of compost are also treated differently in the two methods. In the LCA, the application of compost has a positive impact while the CDM methodology calculates an overall negative impact. This is because the CDM methodology only takes transport emissions from compost into account and does not consider any further emissions or emission reductions such as the substitution of inorganic fertilizer as it is included in the LCA.

In CDM methodologies only greenhouse gas reduction potential of a project is assessed while all other environmental impacts are neglected. For waste management projects such as composting and anaerobic digestion, this seems reasonable as the majority of the environmental impacts are determined by greenhouse gas emissions. However, the sensitivity analysis showed that the system is also sensitive to further impacts such as fossil fuel depletion, particulate matter formation (NH_3 and NO_x emissions) or heavy metal inputs by application of compost. Toxic emissions might even overcompensate the overall beneficial impact from GWP reduction. Here, wider consideration of additional impact factors can create incentives to develop projects that reduce greenhouse gas emission, but additionally also ensure reduction of other environmental impacts.

Generally, large uncertainties exist in the knowledge about greenhouse gas emissions from processes such as composting and anaerobic digestion as well as the application of the produced fertilizer. Because of the sensitivity of these factors more research should be carried out in this area in order to improve the quantification of the amount of gases emitted as well as achieving more evidence on the influence of the specific treatment practices.

ACKNOWLEDGEMENT

We thank Swisscontact and its staff in Bolivia for the opportunity to engage in this project and for insights on Cochabamba. We also acknowledge support provided by the NCCR North-South Program. Finally, the authors express their thanks to C. Collivignarelli at University of Brescia, Italy for his support.

BIBLIOGRAPHY

CIA (2011). *Central Intelligence Agency: The World Factbook.* Webpage: https://www.cia.gov/library/publications/theworldfactbook/geos/bl.html (last accessed 4.11.2011).

CWG (2008). *Global Waste Challenge. Situation in Developing Countries.* Collaborative Working Group on Solid Waste Management in Low- and Middle-income Countries, EAWAG.

Deublein D., Steinhauser A. (2011). *Biogas from Waste and Renewable Resources*. Wiley.

Doka G. (2009). *Life Cycle Inventories of Waste Treatment Systems.* Ecoinvent Report No. 13. Swiss Center for Life Cycle Inventories.

Edelmann W., Schleiss K. (2001). *Ökologischer, energetischer und ökonomischer Vergleich von Vergärung, Kompostierung und Verbrennung fester biogener Abfallstoffe.* Bundesamt für Energie (BFE), Bundesamt für Umwelt, Wald und Landschaft (BAFU).

Forster P., Ramaswamy V., Artaxo P., Berntsen T., Betts R., Fahey D.W., Haywood J., Lean J., Lowe, D.C., Myhreand G., Ngangaand J., Prinn R., Raga G., Schulz M., Van Dorland R. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Frischknecht R., Rebitzer G. (2005). The Ecoinvent database system: a comprehensive web-based LCA database. *Journal of Cleaner Production.* Volume 13, Issues 13–14, November–December 2005, Pages 1337–1343

Gyalpo T. (2010). *Anaerobic digestion of canteen waste at a secondary school in Dar es Salaam, Tanzania.* Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf.

Hartmann J. K. (2006). *Life-cycle-assessment of industrial scale biogas plants.* Dissertation zur Erlangung des Doktorgrades der Fakultät für Agrarwissenschaften der Georg-August-Universität Göttingen.

Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A., Maskell K. (1995). *Climate Change 1995: The Science of Climate Change. Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change.* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)] Cambridge University Press, Cambridge,United Kingdom and New York, NY, USA.

INE (2011). *Instituto Nacional de Estadísticas: Estadísticas del Medio Ambiente.* //www.ine.gob.bo/ (last accessed 10.11.2011).

IPCC (2006). *IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Program [Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tabene K. (eds)]. IGES, Japan.

Klöpffer W., Grahl B. (2009). *Ökobilanz (LCA)*. Wiley.

Matthews E., Themelis N. J. (2007). Potential for Reducing Global Methane Emissions From Landfills, 2000-2030. *In: Proceedings Sardinia 2007, Eleventh International Waste Management and Landfill Symposium,* S. Margherita di Pula, Cagliari, Italy, 1-5 Oct. 2007. CISA, Environmental Sanitary Engineering Centre, Italy.

Obersteiner G., Binner E., Mostbauer P., Salhofer S. (2007). Landfill modeling in LCA - a contribution based on empirical data. *Waste Management*, 27:58–74.

ReCiPe. 2011. *ReCiPe: Homepage.* http://www.lcia-recipe.net/ (last accessed: 04.12.2011)

Spokas K., Bogner J., Chanton J.P., Morcet M., Aran C., Graff C., Moreau-Le Golvan Y., Hebe I. (2006). Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? *Waste Management*, 26:516–525.

Stucki R. (2007). *Klimarelevante Emissionen von Kompost- und Biogasanlagen in Indonesien.* Zürcher Hochschule für Angewandte Wissenschaft (ZHAW), Wädenswil.

Swisscontact (2010). *Diagnóstico de la gestión de residuos sólidos en Cochabamba.* Swiss Foundation for Technical Cooperation.

UNFCCC (2010a). *The Kyoto Protocol Mechanism - International Emission Trading, Clean Development Mechanism, Joint Implementation.* United Framework Convention on Climate Change.

UNFCCC (2010b). *CDM Methodology Booklet.* United Framework Convention on Climate Change.

UNFCCC (2010c). *III.AO. Methane recovery though controlled anaerobic digestion.* United Framework Convention on Climate Change.

UNFCCC (2010d). *III.F. Avoidance of methane emissions through composting.* United Framework Convention on Climate Change.

UNFCCC (2011). *United Nation Framework on Climate Change: Homepage.* http://unfccc.int (lasz accessed 03.06.2011).

Volkart E. (2011). *Environmental impact of different treatment options for municipal organic waste – a case study from Bolivia.* Master Thesis. Swiss Federal Institute of Technology Zurich (ETH). Switzerland

Zurbrügg C., Gfrerer M., Ashadi H., Brenner W., Küper D. (2012). Determinants of sustainability in solid waste management – The Gianyar Waste Recovery Project in Indonesia. *Waste Management*, In Press, Corrected Proof, Available online 11 February 2012.