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Carbon emissions reduction strategies in Africa from improved waste management: A review

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ABSTRACT

The paper summarises a literature review into waste management practices across Africa as part of a study to assess methods to reduce carbon emissions. Research shows that the average organic content for urban Municipal Solid Waste in Africa is around 56% and its degradation is a major contributor to greenhouse gas emissions. The paper concludes that the most practical and economic way to manage waste in the majority of urban communities in Africa and therefore reduce carbon emissions is to separate waste at collection points to remove dry recyclables by door to door collection, compost the remaining biogenic carbon waste in windrows, using the maturated compost as a substitute fertilizer and dispose the remaining fossil carbon waste in controlled landfills.

1. Introduction

This review presents a preliminary assessment of carbon emissions reductions in Africa from Municipal Solid Waste (MSW) management. Main objectives of this study were to provide a clear understanding of emission reductions (ERs) that can be gained by the optimisation of waste management strategies and to fill the important knowledge gap on the impact of carbon emissions due to solid waste disposal across Africa. Studies to date have shown that there is little comprehensive and reliable data on waste management in Africa (Fricke et al., 2007). This study seeks to provide a basis for the design of a protocol of best practice for Municipalities for the implementation of Clean Development Mechanism (CDM) projects. Methane produced at solid waste landfill sites contributes approximately 3–4% to the annual global anthropogenic greenhouse gas (GHG) emissions (Jeon et al., 2007). A broad range of estimates has been made for GHG emissions from landfills (Bogner et al., 2004). However, this study aims to go one step further by assessing carbon emissions for all waste management activities and ultimately developing a philosophy that promotes sustained emissions reduction.

The study was initiated with questionnaires sent to 26 of the 61 territories in Africa, but only six countries have provided valid information to date (Couth and Trois, 2009a). It was concluded that the response rate was reasonable due to a lack of data, rather than a lack of interest. The findings demonstrate the lack of reliable recorded and published data on waste management in Africa, with a clear divide between North Africa and sub-Saharan Africa (Couth and Trois, 2009b). This preliminary study concluded that the scarce data on carbon emissions from waste management in Africa is likely to represent a high percentage of carbon emissions in urban areas. This review analyses available data and knowledge on waste management in Africa with respect to carbon emissions production or reduction potentials, highlights existing constraints/improvements and attempts to make recommendations for implementation of sustainable and appropriate strategies.

2. Waste management practice in Africa

2.1. Introduction

Some countries in Africa have set ambitious targets in the attempt to apply the waste management hierarchy and reduce carbon emissions. For example, the Polokwane Declaration in 2001 in South Africa set targets of 50% reduction in waste to landfill by 2012 with a full zero waste plan to be in place by 2022 (DWAF, 2001). Progress made so far to meet those objectives has not been very encouraging as targets are far too ambitious and insignificant financial resources have been applied at municipal level. These conditions are common in many African countries.

There is a general migration of population from the countryside to urban areas throughout Africa; as a consequence, waste management practices differ vastly between rural and urban areas and within the latter between suburban and peri-urban areas (generally large settlements adjoining urban areas and lacking most infrastructures). For Africa, peri-urban is defined as locations with 250–1000 persons per km^2 with peaks for cities like Nairobi where the population density exceeds 1250 people per km^2 (one person per 8 m^2) (Muniafa and Otiato, 2008).

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2.2. Waste production and composition

Tables 1 and 2 give a summary of waste production and waste composition for urban waste in developing countries. The main carbon emission from waste management practices is methane from landfill gas that is directly dependent on the carbon content of that fraction of the waste, which is readily biodegradable.

Studies presented in Tables 1 and 2 concord that the mean organic/biodegradable/combustible content for urban waste ranges around 56% and waste production is approximately 230 kg/hd/year. It is acknowledged that there are significant variations to figures for biogenic waste content and production in different communities. A study undertaken by Diaz et al. (2007) concluded that the putrescible content of waste from large cities in developing countries ranges from 22% to 61% (e.g. Seoul 22%, Manila 46%, Mexico City 60%, Asunción 61%). Other research by Collivignarelli et al. (2007b) quote the organic waste for developing countries as 41% for low income, 57.6% for middle income and 27.8% for high income communities respectively. It may be noted that these figures are in accord with a study undertaken by the World Bank in 2006 into occupational and environmental health issues of solid waste management (Cointreau, 2006). This concluded that for low-income countries the mean value of biogenic waste was 62.5% with a ±36% variation and the mean waste production was 205 kg/ha/year with a ±25% variation. This World Bank study summarised biogenic waste as a mean of 62.5% for low-income countries 42.5% for medium income countries, and 31% for high-income countries. The United Nations classifies countries in Africa as 68% least developed countries, 28% medium developed and 4% high developed (Couth and Trois, 2009a).

Based upon an African population of around 1 billion of which 40% are currently urban (Couth and Trois, 2009a), this equates to around 50 Mtpa of biodegradable waste (1Bn $*$ 40% urban $*$ 230 kg/hd/year $*$ 56% biodegradable) which is primarily landfilled and contributes to methane production in the atmosphere.

2.3. Rural waste

A large fraction of dry rural waste is scavenged and recycled, and much of the organic waste is used for animal feed or compost. Indeed, organic waste from some cities in Africa has traditionally been used as pig food on a commercial scale, i.e. Cairo, Lusaka (Otieno and Taiwo, 2007; Wehenpohl and Kolb, 2007), to make biomass briquettes (Collivignarelli et al., 2007a) or as substrate for anaerobic digestion (AD) plants (Volegeli et al., 2009). In general, there is a relatively low carbon footprint from rural waste in Africa. In 2004 carbon emissions in the Republic of Chad were 0.0127 tCO_2 per capita compared with a mean of 1.0215 tCO_2 per capita in sub-Sahara Africa (Couth and Trois, 2009b). For this reason, the focus of this paper is on peri-urban and urban waste as waste management and resulting carbon emissions are considered much less of an issue in rural areas.

2.4. Peri-urban waste

In peri-urban areas the responsibility for waste management is generally split between the Municipality and the communities. In

Table 1
Summary of waste production and waste composition.

Country/city	Waste production kg/hd/year	Waste composition % organic	References
Louga/Senegal	110–250	50	Collivignarelli et al. (2007a)
Cape Town/South Africa	–	58	Spies et al. (2007)
Manila/Philippines	146	45	Diaz et al. (2007)
Asuncion/Paraguay	168	61	Diaz et al. (2007)
Mexico City/Mexico	248	60	Diaz et al. (2007)
Chennai/India	219	–	Esakku et al. (2007)
Gujarat/Pakistan	365	–	Farouque and Mahmood (2007)
Morelos/Mexico	–	50	Jean-Baptiste and Bidlingmaier (2007)
South Africa	-	50	Liebenberg (2007)
Dar es Salaam/Tanzania	–	62.5	Otieno and Taiwo (2007)
Cairo/Egypt	–	60	Otieno and Taiwo (2007)
Philippines/Rural	–	60.6–77.8	Paul et al. (2007a,b)
Maputo/Mozambique	182	–	Hunger and Stretz (2006)
Nairobi/Kenya	260	–	Muniafa and Otiato (2008)
Recife/Brazil	–	61.8	Maciel and Jucá (2009)
Mean	228	56	–

Table 2
African waste composition.

	Kenya (Urban)	Uganda (Kampala)	Namibia (Windhoek)	Nigeria (Lagos)	Egypt	Mozambique (Rural)	Mozambique (Urban)	Mean
Food waste	51.5	73.8	36	60	60	29	67	53.9
Paper	17.3	5.4	20	14	10	2	13	11.7
Textiles	2.7	–	–	–	2	–	–	2.4
Plastic	11.8	1.6	16	–	12	4	10	9.2
Grass/wood	6.7	8	–	–	–	–	–	7.4
Leather	0.9	–	–	–	–	–	–	0.9
Rubber	1.5	–	–	–	–	–	–	1.5
Glass	2.3	0.9	13	3	3	1	4	3.9
Metal	2.6	3.1	5	4	2	1	2	2.8
Other	2.7	7.2	10	19	11	63	4	16.7
Total	100	100	100	100	100	100	100	100.0
Inert/non-combustable	7.8	7.2	10	19	13	63	4	17.7
Organic/biodegradable /combustable	58.2	81.8	36	60	60	29	67	56.0

Source: SLR Consulting Ltd. (UK) – unpublished internal waste composition database on African projects.

Lusaka, Zambia, only 20% of the services are provided to only half of the settlements (Tesink and Kabungo, 2006). It is considered that for successful implementation of sustainable waste management, even in a large city like Lusaka, small-scale solutions should be pursued based on the creation of real jobs. The authors consider volunteerism should not be an option as waste management is an important social, economic and environmental requirement. Waste should therefore be managed as a business, and public–private partnership schemes extended to incorporate the informal sector.

Resources or material recovery is a policy that should be embraced in developing countries because it will contribute to the development of organized systematic waste management, result in a sizeable reduction in the amount of wastes that require disposal (Diaz et al., 2007), provide meaningful employment and improve social and environmental conditions. Resource recovery provides a source of income for a relatively large number of people in the lower economic sector. It can be implemented at two levels:

(1) manual recovery of the solid waste by individuals before collection, treatment, or disposal (scavenging), and
(2) a combination of manual and mechanical processes carried out on a relatively large scale in accordance to a plan approved by the local government (materials recycling facility (MRF).

Dirty and clean MRFs require investment and the latter necessitates separate collection of dry recyclates, e.g. paper, cardboard, glass, plastics, metals, textiles, etc. Because of the financial requirements of a dirty MRF, scavenging is a more established process in many developing countries with waste scavenged before collection or directly at landfills and then sold to middle-men who pass it on to the processors.

Scavenging is carried out in three phases (Akamgir et al., 2007). Phase one is the source separation where households separate refuse of higher market value such as papers and paper products, bottles, food containers, plastic materials, tin, glass, metal, old clothes, shoes, etc. and sell it to street hawkers. In the second phase, informal scavengers collect different items of low market value from on-site storage bins/containers and open storage spaces. The items include broken glass, cans, cardboard, waste papers, polythene, rags, polyethylene terephthalate (PET) plastic bottles, coconut shells, metals and miscellaneous commercial waste discarded by householders. The final phase is the recovering of reusable and recyclable materials from disposal sites. Scavengers salvage recyclable wastes as collection vehicles are unloaded at disposal sites.

Cairo is a prime example of managed scavenging (GTZ, 2006; and Otieno and Taiwo, 2007), where a large scale waste reuse and recycling operation is run by the 'Zabbaleen', an efficient and well organized scavenger cooperative group (informal sector) of about 70,000 people. Zabbaleen is involved in the business of waste collection, transportation and processing. This group of people recover and/or recycle between 70% and 85% of all the waste collected, that is then sorted and composted in government financed MRFs (Sherif, 2007). They sort glass, plastics, cardboard, paper, metals, torn clothes and other components of the waste stream. It is reported that the MRFs do not perform well due to poor maintenance, lack of training and inadequate quality control (Sherif, 2007).

Regarding waste collection and scavenging, two different solutions have been analysed for Louga City in Senegal. Firstly, the use of street containers and a door to door collection system (Collivignarelli and Vaccari, 2007). The second alternative is more appropriate as it presents much lower capital costs and provides significant local employment. Furthermore, it is more suitable to the urban structure characterized by areas inaccessible by trucks. Door to door collection guarantees a more effective and widespread way to handle waste. This view is further supported by evidence for Cape Town (South Africa) where informal settlements are recognised and therefore receive municipal waste collection and cleansing services (McKinnon, 2009). Because vehicle access in informal settlements is difficult, the solution in Cape Town is driven by a community service option. Waste collection and cleansing services are tendered to the private sector. All labour and supervision must be provided from the informal settlement being serviced, with a minimum hourly rate pay. Each labourer has a zone of 400 dwellings to carry out weekly collection of waste in bags given to residents and takes them to a central collection point. The labourer is also required to clean and keep the street zone clear of litter and is given a wheeled bin or trolley to take the bags to a central transfer point, before final disposal to landfill.

Financing is fundamental to the collection of waste. It should be more cost effective for the public sector (Municipality) to collect waste, however it is evident from a number of papers (Freeman and Mgingqizana, 2002; Wehenpohl and Kolb, 2007) that budget prices provided by private operators are more often cost effective due to political buy in from officials and Municipal Councillors into the process, corruption with officials enriching themselves by commanding bribes for any approval, allocation of contracts, economies of scale and requirements of a positive cash flow to pay staff, materials, fuel and equipment (Liebenberg, 2007).

Privatisation of the waste collection services is dependent upon Municipality's ability and willingness to pay. In Botswana, many municipalities cannot pay for the service and those who can do not have a willingness to pay, consequently waste management is often not attractive to the private sector, forcing State funding of the solid waste management system (Segosede, 2008). In Addis Ababa, classified as one of the dirtiest cities in the world, there is a poor waste collection service (Esan and Wenborn, 2007). Waste is collected in wheel-barrows, and by donkey and carts, and placed in skips which are then transported to dumps for disposal. There is a lack of funding for waste management services. In 2002, only 1% of the total municipal budget was for solid waste management (by normal international standards this should be 20–40%). To compound matters, there is also no national waste management strategy in Ethiopia.

In developing counties, residual waste is predominantly disposed in uncontrolled dumps, and scavenging takes place on sites as waste is off-loading from vehicles (Paul et al., 2007b). These dumps do not have engineered containment. Landfill gas is not collected and combusted and consequently escapes to atmosphere. Uncontrolled dumping of waste is the main source of carbon emissions from waste management in developing countries (Cossu and Piovesan, 2007).

2.5. Urban waste

It is reported that waste management is often low on the agenda for officials in developing countries (Ferreira et al., 2007). Inadequate urban solid waste management is related to the restricted funding of public services and the lack of technical and human resources. Others aspects which also contribute to this situation include the low level of awareness of municipal authorities concerning the environmental and public health impacts resulting from mismanagement of the waste systems, the cultural aversion towards waste – relating in many cultures to impurity, sin and the dead – that systematically contributes towards placing Municipal Solid Waste management last among local priorities, the population growth (aspiring to developed country standards of living and consumption patterns) and its pressure on resources and waste production. A good management system relies primarily on good household waste collection, a good street cleaning performance and provision of sanitary landfills.

Income for household waste collection is generally raised from a municipal tax. Maputo, in Mozambique, has sought a variation on this through a tax on electricity. This was opposed and therefore changed into a standard tax for electricity supply (Hunger and Stretz, 2006). However this tax only provided sufficient revenue for waste collection from approximately 50% of households. Collection and disposal services in Lusaka, Zambia, are funded by cross-subsidisation from the more affluent areas to the peri-urban areas (Tesink and Kabungo, 2006). The project concludes that for successful implementation of sustainable waste management, even in a large city like Lusaka, small-scale solutions should be pursued to promote job creation and contribute to improvement of living standards (Tesink and Kabungo, 2006).

Four countries in the European Union (EU) and a state in the US have introduced landfill bans for certain untreated waste to be disposed to landfill (DEFRA, 2009). However, this is not considered applicable to the majority of countries in Africa who do not have sanitary landfills for the disposal of their waste. With the landfill bans, countries such as Germany are reporting only 1% of the waste produced being landfilled with the corresponding reduction in methane emissions (DEFRA, 2009).

3. Carbon emissions from waste

This section researches carbon emission generated from waste management activities and explores the strategies in place to promote emission reductions (ERs) such as Clean Development Mechanisms (CDMs) projects, waste recycling, composting and disposal.

3.1. Clean Development Mechanism (CDM)

The Kyoto Protocol, on which CDM is based, was a result of the Earth Summit in Rio de Janeiro in June 1992 (United Nations, 1992, 1997). The Rio Earth Summit debated sustainability as defined in the Brundtland Report 'Our Common Future' (WCED, 1987) which highlighted the three fundamental components of sustainable development as the environment, the economy and society. Regarding waste management a "sustainable landfill" should be one that has stabilised within one generation (Morris and Scharff, 2009).

The outcome of the Rio Earth Summit was a series of non-mandatory treaties (agreements, including the United Nations Framework Convention on Climate Change (UNFCCC)) that were later updated into legally binding protocols. Through the Kyoto Protocol some industrialized nations, all defined as Annex I countries, agreed to legally binding reductions in GHG emissions of an average of 6–8% below 1990 levels between the years 2008–2012. This is the first emissions budget period (Lee et al., 2007). Of 180 nations have ratified the Protocol except for the USA. The Kyoto Protocol has three mechanisms to achieve this through emissions trading – known as "the carbon market", the Clean Development Mechanism (CDM) and joint implementation (JI).

The CDM provides for Annex I Parties to implement project activities that reduce anthropogenic emissions in non-Annex I Parties. The CDM has two key goals, to assist developing countries that host CDM projects to achieve sustainable development and to provide developed countries with flexibility for achieving their emission reduction targets, by allowing them to access credits from emission reduction projects undertaken in developing countries. These mechanisms allow Parties to trade a proportion of their national emissions to other nations, based on emission units generated by reductions or sequestration of GHGs that are normalised into a single functional unit according to their global warming potential, which is calculated by comparison to a similar weight of carbon dioxide (CO_{2e}) (ICBE, 2008).

The rules for CDM projects to receive CERs are complex. Each Annex I party has a cap for ERs. Consequently, if they exceed their ER cap they can then can trade with other Annex I and developing countries. International emissions trading under the Kyoto Protocol provides a framework for trading between Annex I Parties of Assigned Amount Units (AAUs) together with other emission units which are each equivalent to 1 tonne CO_2 (CO_{2e}), i.e. CERs (CDM), ERUs (JI), and Removal Units (RMUs) (land-use, land-use change and forestry (LULUFF)). International emissions trading under the Kyoto Protocol can be linked to regional or domestic trading schemes, the most notable of which is currently the European Union Emissions Trading Scheme (EU-ETS) (European Union, 2006).

CDM must be hosted by non-Annex I Parties (host Parties) that have ratified the Kyoto Protocol and established a designated national authority (DNA), developed by public or private entities authorised by the relevant host Party and Annex I Party involved in the project activity.

It must be validated by a designated operational entity (DOE) in accordance with the CDM project eligibility and participation requirements, including the use of an approved baseline and monitoring methodology.

It is finally registered by the CDM Executive Board (EB) after review by a Registration and Issuance Team to ensure compliance with the international rules and, once commissioned and operational, verified and certified by a DOE as resulting in real, additional, measurable and verifiable reductions in GHG emissions below an approved business as usual baseline scenario.

In addition to the UNFCCC and EU-ETS carbon markets for CERs, there is also the voluntary carbon market of voluntary emission reductions (VERs) (Ecosystem Marketplace, 2008). These are purchased by companies to fulfil voluntary corporate GHG reduction targets to demonstrate that the company is *carbon neutral*.

There is a list of 15 sectors for CDM projects (United Nations, 2006), one of which is 'Waste handling and disposal', which includes recycling, composting and landfill gas generation. Eligibility for the CDM is premised on the requirement that a project will not proceed without the financial incentives provided by the creation of saleable CERs (Lee et al., 2005). Reductions in emissions must be real, measurable and additional to any that would occur in the absence of the certified project activity. There are various types and scale of CDM project:

- Large-scale project activities (CDM);
- Small-scale project activities (CDM–SSC);
- Afforestation and reforestation project activities (CDM–AR); and
- Small-scale afforestation and reforestation project activities (CDM–SSC–AR).

3.2. CDM projects in the waste handling and disposal sector in Africa

The main practice for reducing carbon emissions from waste management is the capture and combustion of landfill gas, with energy recovery where practical. However, materials recycling and composting prior to landfill is being established in developing countries. Materials recycling and composting is higher up the waste hierarchy (prevent/minimise; prepare to reuse; recycle and compost; recover; then dispose). Waste recycling and composting should provide more emission reductions than collection and combustion of landfill gas with energy use (e.g. electricity generation), as the landfill gas is prevented from being generated, rather than around 50% of the gas being recovered and combusted. The reuse of products and the recycling of materials provide emission reductions against the manufacture of new materials from virgin sources. Recycling and composting should therefore provide more carbon emission reductions and potential CDM income than landfill gas combustion with energy recovery.

In developed countries the current favoured treatment option for organic waste (separately collected food waste) is anaerobic digestion (AD) as this generates renewable energy and creates a digestate fertilizer. However, the capital cost and complexity of the operation and maintenance of equipment is greater than for materials recycling and composting facilities. Consequently more materials recycling and composting schemes are being developed in non-Annex I countries than AD projects.

The total carbon content of MSW can be divided into two main categories – fossil carbon and biogenic carbon (Moller, 2007). It may be noted that metal and glass contain very little and no carbon respectively. Fossil carbon is, in general, non-degradable and it is found in plastic and synthetic fabric. IPCC guidelines for GHG inventories do not allow for the use of landfills as carbon "sinks". Nevertheless, it is evident that the extremely slowly degradable fossil carbon such as lignin and hemi-cellulose will form stable humus compounds that will remain in the landfill for hundreds of years. Consequently, there is recognition that landfills can provide carbon sinks for fossil carbon.

Biogenic carbon is mainly found in biodegradable fractions such as organic kitchen waste and paper. Moller (2007) modelled the emission offset of six EU compliant waste management scenarios:

- Incineration (electricity only);
- Incineration (CHP);
- MBT 1 – biostabilization before landfilling;
- MBT 2 – RDF production + composting before landfilling;
- MBT 3 – RDF production + biogas production for energy recovery; and
- Landfilling with methane capture.

Table 3 clearly shows that landfill, even with gas capture and combustion, has far greater carbon emissions than other waste disposal option. Energy from Waste (EfW) with CHP effectively has net negative carbon emissions, with the energy gained from waste combustion offset against the combustion of fossil fuel. The majority of the territories in Africa are however unlikely to be able to fund these treatment technologies, and even if they do receive capital funding to construct, they may not provide revenue funding to operate. Scavenging, composting, and landfilling of the remaining fossil carbon appear the most sustainable solutions. It is clear from Table 4 that certain regions of the world, notably Africa, have lagged behind in the development of CDM projects. In addition, some CDM project sectors, notably landfill gas, have attracted attention for their failure to deliver projected Certified Emission Reductions (CERs).

At the start of this study there were two categories of validated CDM waste handling and disposal (landfill gas capture and electricity generation) projects on the UNFCCC web site:

1. AM0010: Approved baseline methodology 'Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law' July 2004 (United Nations, 2004a).
2. ACM0001: Approved consolidated baseline methodology 'Consolidated baseline methodology for landfill gas project activities' (United Nations, 2004b).

The UNFCCC have a policy that guidance cannot be retrospectively applied. Therefore, projects registered in the period when AM0010 applied are not subsequently required to comply with the revised ACM0001 baseline methodology and vice versa. There are two projects validated under AM0010, both with eThekwini Municipality in Durban, South Africa and seven CDM projects validated in the rest of Africa up until August 2008 (Table 5).

3.3. Recycling

In general, the energy consumed in transporting recyclables to reprocessing factories is small in comparison to the energy requirements for the excavation, production and transport of virgin material (WRATE, 2009). Recycling has GHG benefits together with energy and water savings, as details in the Department of Environment and Conservation New South Wales report of 2005 for recycling paper/card, liquid paper board, glass, aluminium, steel, high density polyethylene (HDPE) and polyethylene terephthalate (PET) (NSW, 2005). GHG benefits of recycling range from 15.17 tCO_{2e} per tonne of aluminium recycled, to −0.25 tCO_{2e} per tonne of PET recycled. The long distances between the respective generation areas of recyclable materials and the industries required to process such materials can result in high transport costs, complicating the implementation of viable waste recycling initiatives. The transportation costs of recyclables are often prohibitive (Blight and Mussane, 2007). This paradox arises because the full environmental costs of the processing of raw materials are not reflected in the price of consumer goods. Likewise, the cost of conventional waste disposal is low in comparison to the cost of recycling, since full environmental costs of waste disposal are not reflected. Economies of

Table 3
Waste treatment technology greenhouse gas emission ranking (Moller, 2007).

Scenario	1. EFW	2. EFW with CHP	3. MBT and landfill	4. MBT, RDF and landfill	5. MBT with AD	6. Landfill with gas capture
Emissions offset $KgCO_2$/tonne waste	12	−216	104	224	210	502
Ranking	2	1	3	5	4	6

Abbreviations: EFW: energy from waste (Incinerator); CHP: combined heat and power; MBT: mechanical biological treatment; RDF: refuse derived fuel; AD: anaerobic digestion.

Table 4
CDM validated waste projects at August 2008 (http://cdm.unfccc.int/Projects/Validation/index.html).

Region	Countries	Validated CDM Projects
South and Central America	Brazil, Chile, El Salvador, Peru, Argentina, Ecuador, Uruguay, Mexico, Columbia, Cuba, Guatemala and Panama.	84
China and Far East	China, Philippines, Thailand, Korea, Indonesia, Vietnam	63
Eastern Europe, Middle East and Central Asia	Armenia, Moldova, Georgia, Israel, Kyrgyzstan, United Arab Emirates, Jordon, Syria, Bangladesh, Malaysia	23
Africa	Côte d'Ivoìre, United Republic of Tanzania, Egypt, Tunisia, Senegal, South Africa	7

Table 5
AM0010 and ACM0001 and validated CDM projects in Africa (CDM pipeline web site).

No.	Name	Country	ERs (tCO_{2e}/year)	Validation date
AM0010 validated CDM projects in Africa				
1	Mariannhill and LaMercy		68,800	September 2005
2	Bisasar Road		350,170	July 2006
ACM0001 validated CDM projects in Africa				
1	Akouédo	Côte d'Ivoìre	943,546	December 05
2	Mtoni	United Republic of Tanzania	103,321	February 06
3	Alexandria	Egypt	371,526	March 06
4	Djebel Chekir	Tunisia	369,664	March 06
5	9 Bundled Sites	Tunisia	317,909	March 06
6	M'beubeuss	Senegal	131,322	March 07
7	Alton	South Africa	35,586	July 07

Abbreviations: AM0010: approved baseline methodology 'Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law' July 2004 (United Nations, 2004a), ACM0001: approved consolidated baseline methodology 'Consolidated baseline methodology for landfill gas project activities' (United Nations, 2004b), ERs: emissions reductions.

scale together with a lack of recognition of true costs act such that the greater demand for virgin goods means that producing goods from virgin materials is often cheaper. This is often aggravated by limited competition for marketing of the recyclable materials (Sauramba, 2002). CDM credits are not available for the difference in the carbon emissions needed for virgin material production against reprocessed material production (i.e. plastics (fossil carbon), metals and glass), although the basis for the calculation should be the difference of the emission reductions with and without the project (Astrup, 2009).

It is reported by Diaz et al. (2007) that three factors generally contribute to the practice of material recovery in developing countries:

(1) economic conditions – a relatively undeveloped or developing economy of the country,
(2) material and energy conservation – shortage of inexpensive virgin materials which are essential to local industries, lack of affordability or production capacity for items that can be remedied by recovery of useable materials from wastes, and shortage or relatively high cost of energy, and
(3) soil conservation – soils that are of low quality or that are being rapidly depleted of organic matter. Community contractors can be established to scavenge and recycle waste, but a community contractor needs financial support to set up recruiting of staff, purchase of equipment, operational procedures and improving living conditions (Liebenberg, 2007).

Income from recycling is uncertain and dependent upon material and manufacturing markets. The estimated income that could be generated from the sale of recyclables for the 'Zero Waste' project in Durban, South Africa could not cover the monthly costs of running the project (Matete and Trois, 2008). Whilst recycling waste does reduce the amount disposed to landfill and effectively saves the municipality costs in the provision and operation of a landfill, this is not reflected in the income from recyclable materials. In the UK, charities and organisations can claim Recycling Credits to the value of the cost of the disposal, including Landfill Tax, and hence waste is diverted from landfill. Landfill tax in the UK is currently equivalent to €44 (£40) and is set to rise to €79 (£72) by 2013. In Africa, the use of uncontrolled dumps makes disposal of waste cheaper and more popular than recycling. For the latter to occur the recycling income must cover the cost for scavenging and transporting the waste materials (Stotko and Trois, 2006). Municipalities should not expect to make large profits from recycling ventures. The most important benefit to the Municipality will be an extension of the life of existing landfill sites, job creation and cleaner communities (Blight and Mussane, 2007).

3.4. Composting

Composting is a two-stage waste treatment process. Collected waste should be sorted and the biowaste screened to remove plastics and metals, and then shredded. Biodegradable waste may then be composted in open windrows or closed vessels for 4 weeks, with controls on vermin, air injection, moisture control, and the piles turned three to five times a week (Paul et al., 2007a). Following this the compost should be stored in windrows for two to three months to mature. Subsequently it can be sieved (<10 mm) to remove large particles and spread to land as a soil substitute. Small amounts of methane (Global Warming Potential (GWP) 21 × CO_2) and nitrous oxide (GWP 296 × CO_2) may be generated by the composting process and the maturated material (Linzner and Mostbauer, 2005).

The application of compost as organic fertilizer also promotes, over time, a build up of carbon which could prove to be a "sink" for the carbon sequestered in the soil (Barth and Favoino, 2005). Soils play a major role in the global carbon cycle and the application of compost can therefore mitigate climate change effects by retarding CO_2 release into the atmosphere. The carbon saving from energy used in the production of fertilizer should also be included. Carbon emissions for waste composting can be calculated as given in Table 6.

The benefits of composting include reduction of waste volume for waste disposal, reduction of organic content within the local disposal site, recovery of organic materials and production of soil enhancer/organic fertilizer, reduction of chemical fertilizer application within the municipality, integration of additional livelihood

Table 6
Carbon emissions from waste composting (Linzner and Mostbauer (2005).

System element	Emissions (kg CO_2-equiv./t compost)	%
Separate collection of biowaste	31.7	18.4
Delivery of biowaste: collection centres to processing facility	0.9	0.5
Transportation processes	6.6	3.8
Processing facility – consumption of electricity	2.7	1.6
Processing facility – consumption of diesel fuel	8.2	4.8
Composting plant "Lobau" – consumption of diesel fuel	13.3	7.8
Composting plant "Schafflerhof" – consumption of diesel fuel	4.6	2.7
Delivery of compost: composting plants to direct application within Viennese agriculture	3.4	2.0
Delivery of compost: composting plants to collection centres	1.2	0.7
Composting process: emissions due to biodegradation processes	99.2	57.7
Total climate relevant emissions	171.9	100

opportunities, support of poorer farmers and reduction of ground and surface water pollution (Paul et al., 2007a).

Composting of MSW is not new in Africa. Garden refuse, disposed on landfills separated from the main waste stream, has traditionally been composted in Cape Town and Johannesburg in South Africa (Coetzee et al., 2007). However, the quality of the compost is generally poor as the garden refuse often arrives on site 'contaminated' by plastic bags or other waste fractions.

3.5. Disposal

Waste disposal CDM projects are primarily 'landfill gas projects'. The requirement for small-scale projects (CDM–SSC–AR) is that they should be of one of the following types (Baker and McKenzie, 2008):

- Type (i): renewable energy project activities with a maximum output capacity equivalent to up to 15 mW (or an appropriate equivalent);
- Type (ii): energy efficiency improvement project activities which reduce energy consumption, on the supply and/or demand side, by up to the equivalent of 60 GWhr per year; or
- Type (iii): other project activities that both reduce anthropogenic emissions by sources and directly emit less than 60 kiloton of carbon dioxide equivalent annually (17/CP.7, paragraph 6(c) as amended by 1/CMP.2, paragraph 28).

For landfill gas, the maximum size of a municipal landfill whose quality for these three types of small-scale projects is illustrated in Table 7.

Table 7 indicates that a landfill size up to around 10 Mm^3 will be classified as a small-scale project where the landfill gas is combusted and electricity generated in reciprocating engines or a turbine. Where the gas is combusted in a nearby industry, the size of the landfill which qualifies for a small-scale project is around 3 Mm^3, but where the gas is solely combusted in a flare then the size of the project is reduced to around 1 Mm^3. However this ruling is not applied and there are many CDM landfill gas projects where gas is flared from landfills which are larger than 1 Mm^3. The above calculations are based on the GWP of methane against carbon dioxide, landfill gas constituted by 50% methane, 0.000714 t/m^3 methane density and 3260 tCO_2 equals 1 GWhr (ICBE, 2008).

There is now a reasonable amount of data on the volumes of landfill gas generated from landfills. The UK Environment Agency requires landfill sites to be designed with low permeability liners (1 m of clay at 1×10^{-9} m/s or equivalent), low permeability capping (1 m soil over, 0.5 m drainage layer over, impermeable mineral layer (clay, bentonite, HDPE or GCL), over, gas drainage layer), landfill gas extraction where gas generation predictions are greater than 50 m^3/h, gas utilisation where practical and enclosed flare design, with gas extraction wells installed within 6 months of disposal (UK–Environment Agency, 2004). The basis for these design requirements are to collect and combust 85% of the landfill gas generated. However, these landfill design parameters do not apply to the disposal of waste in dumps, controlled dumps, or sanitary landfills in developing countries. The World Bank undertook an assessment of the delivery of carbon finance projects (World Bank, 2007a). This concluded that of 15 landfill gas projects, the actual recovery was 47.3% of the predicted recovery. The World Bank subsequently undertook a comparison of forecasts and reported methane recovery rates at selected landfills in developed countries (World Bank, 2007b). This reported that for 13 out of 14 CDM and JI landfill gas projects, the emission reductions fell well short of Project Design Document (PDD) (UNFCCC, 2009) estimates due to inappropriate application of landfill gas models, site conditions which limit landfill gas recovery and estimates of collection efficiency that do no adequately cover for poor site conditions, fires, aerobic conditions, poor well radius of influence due to water tables, dry waste and inadequate extraction systems allowing air intrusion (Rettenberger (2009).

Other studies have concluded that approximately 50% of the gas generated may be extracted from un-engineered landfills (Cavallari, 2005) although figures as low as 35% are quoted (Spokas et al., 2005). This means that often with landfill gas extraction systems up to 65% of the tCO_{2e} is emitted to atmosphere. There is however little certainty to these figures and any assessment for GHG emissions from landfill should consider the sensitivity of a range of figures. It is quoted that Iranian landfills recover 75% of the landfill gas calculated by LandGEM (Atabi et al., 2009).

For landfill gas projects, income can be gained through Certified Emission Reductions (CERs), electricity off-set CERs credits (emissions that conventional power plants otherwise would have produced) and electricity (energy) sale. However, there are risks in the quantity of landfill gas that is available with time, the infrastructure development costs, the uncertainty and time in gaining UNFCCC project verification, the long term income from the sale of CERs, the investment cost (landfill gas equipment costs have increased significantly in recent years and are dependent on the quality and specification) and life and maintenance costs for equipment particularly as the corrosive potential of landfill gas is variable (Espinoza et al., 2007). The risks need to be assessed for varying gas generation scenarios.

The performance of CDM projects is measured by the CER issuance success rate = CERs issues/CERs calculated in Project Design Document (PDD) for the same period. As of 1st February, 2008, registered landfill gas projects having reached the issuance step had a CER issuance success rate of 37% (Crawford, 2008).

There is also the question whether it is viable to introduce landfill gas CDM projects on completed and old landfills, which are a significant source of carbon emissions, given that gas generation patterns are highly site, waste composition and climate specific. Suggestion has been made to aerate old landfills for rapid stabilisation of organic matter (Ritzkowski et al., 2003. Van Vossen et al., 2009). However, the practicality and viability of this is

Table 7
Approximate landfill size, small scale CDM projects (calculation based on Baker and McKenzie (2008)).

Type	Units	Gas flow	Landfill size
Type (i): Up to 15 MW		m^3/h	m^3
LFG electricity project	1 MW=	650	
	15 MW=	9750	
	1 Mm^3=	1000	
	15 MW=		9,750,000
Type (ii): Up to 60 GWhr/year			
LFG energy project	1 GWhr/year=	50	
	60 GWhr/year=	2978	
	60 GWhr/year=		2978.360
Type (iii): Up to 60,000 t CO_{2e}/year			
LFG flaring project	60,000 tCO_{2e}/year=	914	913,607

questionable for landfills in developed countries let alone landfills in Africa.

Landfill gas can be combusted and the energy used for electricity generation and distribution into the local grid. The UNFCCC preference for landfill gas projects is electricity generation and not sole flaring. The AFREPEN (African Energy Policy Research Network) has looked at the potential for electricity generation from urban solid waste for a number of countries in Africa (Habtetsion et al., 2004). However, the manufacturers of landfill gas reciprocating engines do not consider that electricity generation is viable in many countries in Africa as the engines cannot be maintained. With the exception of South Africa, there are no Registered CDM landfill gas-to-electricity projects in sub-Sahara Africa.

Methane emissions from developed countries are expected to decrease with waste management moving higher up the waste hierarchy whilst emissions from developing countries are expected to increase with the rapidly expanding populations, increasing waste production, a lack of formal recycling programs and a shift away from open dumps to sanitary landfills to improve health conditions (Crawford, 2008).

Methane emissions for various types of landfill cover are reported as (Corti et al., 2007):

- LDPE/clay composite: 0.45 Nl/h/m^2 (0.225 Nl/h/m^2 @ 21 $*$ CO_2)
- Clay: 2.32 Nl/h/m^2 (1.16 Nl/h/m^2 @ 21 $*$ CO_2)
- LPDE lapped: 6.27 Nl/h/m^2 (3.135 Nl/h/m^2 @ 21 $*$ CO_2); and
- Daily cover: 15.55 Nl/h/m^2 (7.775 Nl/h/m^2 @ 21 $*$ CO_2).

For covered landfills in developing countries emission values range from 2.26 to 16.6 gCH_4/m^2/day with the majority of methane emissions from point sources located near to slopes and cell edges (Akerman et al., 2007). For the EU landfill capping design, emissions are generally below 0.004 gCH_4/m^2/day. Emissions from active disposal areas are around 38 gCH_4/m^2/day.

There is currently considerable research and interest in the oxidation of methane in soil covers as the methane emissions are a measurable anthropogenic GHG. European Union countries are researching the use of compost covers to reduce GHG emissions from restored landfills (Groengroeft et al., 2009; Huber-Humer and Lechner, 2009; Kjeldsen et al., 2009; Straka et al., 2009). There was notable research in the US in the late 1990s to investigate the potential for the oxidation of methane in landfill covers (Bogner et al., 1997). Landfills are the second largest source of methane emissions after ruminant animals in the US, contributing 2% of their anthropogenic methane emissions (Spokas et al., 2009). Historically 10% methane oxidation in cover materials has been allowed in the US but recent investigations focused on GHG emissions have indicated values of around 35% oxidation (Spokas et al., 2009). It was however previously considered that oxidation of methane in landfill covers in the US was marginal and should not be taken into account in the calculation of methane emissions from landfills. The figure of 35% is higher than the 13–30% oxidation achieved in specific bio-cover trials in Denmark (Kjeldsen et al., 2009). In the UK, GasSim (Gregory et al., 2003) included methane oxidation in soil cover materials but it was excluded from GasSim 2 (Gregory and Rosevear, 2005) as there is no certainty of the extent of the oxidation.

It is too costly and impractical to construct low permeability cover for landfills across Africa. Most of Africa has a semi-arid climate and low permeability compacted clay layer (CCL) landfill capping in such climates is subject to cracking, release of landfill gas and infiltration of water. The alternative is to replace the compacted clay layer with a soil that acts as an infiltration retarder and storage layer (Blight et al., 2003). It is concluded that as most landfills in Africa are dumps, there is unlikely to be much methane oxidisation in soil cover layers.

4. Finance and delivery

To improve waste management it is clear that there is not one answer to suit all. Local communities need to be consulted on systems which are proven elsewhere, cost effective and sustainable. Governments have sought to apply a number of policy instruments in the field of pollution and waste management:

- Command-and-control instruments (directive-based regulation) – direct legislation (e.g. landfill bans);
- Economic instruments (economic incentive-based strategies) – polluter-pays principle (e.g. landfill tax);
- Voluntary agreements (moral incentive-based strategies) – little influence in developing countries;
- Information instruments (information-based strategies) – little influence in developing countries.

Direct regulations are only of use if they are enforced. Economic instruments can provide greater incentive than direct legislation providing they are fair and are enforced, as listed in Table 8. Many economists believe that developing countries are not ready for economic instruments due to a lack of financial and human resources, lack of institutional capacity and thus lack of monitoring and enforcement, poorly developed markets and legal systems, lack of understanding of how markets operate, corruption, lack of transparency and lack of adequate equipment and data (Matete and Trois, 2008). Furthermore, where economic instruments have been applied they have not been effective because they have simply been imported from developed countries without consideration of local circumstances.

The institutional issues that apply to many developing countries include lack of legislative framework for integrated MSW management, lack of integrated management of MSW system components, under-funding of Municipal Solid Waste services and lack of effective educational programs to encourage source separation of organics and dry recyclables (Lopes et al., 2007). The delivery issues for waste management services include low levels of recycling, predominance of scavengers as agents in the recycling component of typical systems, low or nonexistent organics diversion, uncertainty in estimates of current and future MSW generation in the region, low degree of participation of private sector companies in recycling and waste diversion activities and environ-

Table 8
Economic instruments for waste management (Godfrey and Nahman, 2007).

Instrument	Example	Purpose
Virgin material tax	Aggregates Levy	Discourage use of virgin materials, encourage reuse
Product charges	Plastic bag tax	Decrease production, use and disposal of plastic bags
User charges	Household waste charges	Reduce waste at source, encourage recycling
Disposal charges	Landfill charges	Decrease amount of waste disposal
Deposit-refund schemes	Bottles, batteries	Encourage appropriate disposal/return for recycling (especially useful for hazardous waste products)
Recycling credits		Encourage recycling
Tax concessions/subsidies		Encourage recycling and reuse

mental impacts from unacceptable disposal (dump) sites (Lopes et al., 2007).

The seven characteristics of waste management in developing countries (Ball, 2006) are reported as:

1. *Priority standing:* Waste management does not have a priority standing in the Maslow hierarchy of needs;
2. *Political will:* Waste management and the environment are not high on the political agenda in developing countries, although the economy generally is. The environment is subservient to economies, but with the effects of global warming political will should focus more on the environment to enhance the economic and therefore the social position;
3. *Lack of resources:* Lack of resources with knowledge and experience of management of the waste hierarchy;
4. Local factors and local culture for waste management;
5. Systems and information. Few reliable systems and technologies in place;
6. Unacceptable waste management practices;
7. *Donor funding:* Donor funding is available to developing countries, however it tends to occur once off and capital is not continuous for long term operation and maintenance, e.g. Mpererwe landfill, Kampala, Uganda.

Principles for waste management in developing African countries are understanding the local conditions, obtaining official and political buy-in, ensuring the basic cleansing systems are in place, being aware of significance of appropriate technology, looking for significant improvements through key interventions and providing training and ensuring on-going involvement (Ball, 2006).

CDM landfill gas projects have been referred to as ‘low hanging fruit’ (Strachan and Pass, 2009) to provide income to developing countries whilst reducing carbon emissions. Lee et al. (2005) commented that the cost of reducing GHG emissions in the developing world was \$1–\$4/tonne of CO_{2e} (carbon dioxide equivalent). This was considerably cheaper than the cost of achieving comparable carbon emission reductions in developed countries at a cost of around \$US15/tonne of CO_{2e}. The financial viability and project risks should be assessed by determining the cash flow and net present value (NPV) for varying scenarios. The current price (2009) paid per tonne of CO_{2e} is around €10, whilst the cost to design, build, finance and operate a CDM project should be less that €5/t CO_{2e}.

Solid waste management strategies and technologies are driven by developed countries. Less developed countries face difficult solid waste management problems (Wagner et al., 2007). In Africa, there is no formal waste treatment before disposal. Most people in Africa cannot afford to pay for waste collection and disposal and generally fees cannot be collected for implementation of projects.

5. Conclusions and recommendations

This review demonstrates the cost benefit of organised scavenging and composting of waste so that such schemes may be funded and developed through the CDM process, that there is effective carbon emissions reduction benefits of such schemes against the extraction and combustion of landfill gas and that a positive social benefit is developed through job creation, education and environmental improvement.

The majority of activities aiming at carbon emissions reduction occur in developed countries. Carbon emissions per capita in developing countries in sub-Saharan Africa are a quarter of the average of developed countries, and half the emission ceiling for the world to control global warming (Couth and Trois, 2009b). However, as the population in Africa becomes more urbanised and seeks developed world standards, waste and GHG emissions from waste management will increase. The urban and peri-urban waste in developing countries contains a high percentage of biogenic organic carbon which is converted into methane during biodegradation in landfills. If this waste can be managed with a beneficial output then the GHG from waste management can be reduced. If this is not initiated, then GHG emissions from waste management in Africa will continue to rise.

To improve waste management in developing countries it is essential to set achievable standards and objectives. Local involvement is important in terms of problem definition, strategy and problem solution. The role of education and environmental awareness as well as public–private participation is key in the improvement of waste management in developing countries.

All cities in developing countries, and sometimes also in industrialized ones, have an extensive solid waste informal sector that operates at the edges of a more formal solid waste system, often driven by groups of scavengers from local communities (Diaz et al., 2007; Spies et al., 2007; Matete and Trois, 2008). The informal sector’s primary activity is the separation of organic and recyclable material for income generation. In most countries, there are no national guidelines or polices to the involvement of the informal sector in municipal waste management. Therefore, polices need to be formulated and implemented at municipal level. Representatives from the informal sector need to be included in the preparation of waste management strategies and contracts. Involving the informal sector can create employment, generate income and “clean up” the environment.

For a real overview of the economical impacts of the informal sector within solid waste management, in addition to the directly measurable costs and benefits, the indirect issues have to be considered (Wehenpohl and Kolb, 2007). This is generally not easy and not all of them can be considered. However, one possibility is financing the environmental improvements of the informal sector through CDM. The GHG impacts of the informal sector can be measured as ERs and costed as CERs. The negative social impacts associated with the recycling processes and illegal disposal should be quantified against the GHG benefits of informal scavenging/recycling.Priorities and objectives for developing countries should be (Farouque and Mahmood, 2007):

- More focussed community awareness programs to be conducted,
- Creating employment for the unemployed youth,
- Garbage bags to be distributed amongst households,
- Segregation of inorganic wastes at source,
- Recycling of organic wastes into compost,
- Control of recycling market volatility by Governments,
- Managing gas and leachate from the disposal of waste.

From this review of waste management practices across Africa, the most practical and economic ways to manage waste in the majority of urban communities are considered to be:

- To apply the “dry–wet” separate collection model by door to door collection;
- To compost the remaining biogenic carbon waste in windrows, using the maturated compost as a substitute fertilizer. Non-compostable materials will need to be removed from the waste prior to composting; and
- To dispose of remaining fossil carbon waste in sanitary landfills. If biogenic waste is removed, mainly fossil carbon and inert waste will be landfilled, and the landfill should not require landfill gas extraction systems.

The carbon-reduction benefits of organised waste scavenging, composting and disposal schemes should be investigated in greater detail with the objective of possible inclusion in the CDM registration processes. The issue for the UNFCCC Executive Board (EB) will be monitoring and control of the organised scavenging to demonstrate that the predicted carbon emission reductions from this activity are actually delivered. It is noted that Veolia already has a registered street cleansing and composting CDM project in Alexandria, Egypt (Crawford, 2008). Support from the Designated National Authority (DNA) in Africa could be sought for this application.

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References

Akamgir, M., Bidlingmaier, W., Glawe, U., Martens, J., Sharif, L.A., Visvanathan, C., Stepniewski, W., 2007. Safe and sustainable management of Municipal Solid Waste in Khulna city of Bangladesh. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Akerman, A., Budka A., Hayward-Higham, S., Bour, O., Rally, D., 2007. Methane emissions measurements of different landfills. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Astrup, T., 2009. Estimating contents of biogenic and fossil carbon in municipal solid waste. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Atabi, F., Harati, S.A.N., Qanbari Sagharlu, N., 2009. Calculation of CH_4 and CO_2 emission rate in Kahrizak landfill site through Landgem mathematical model. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Baker, McKenzie, 2008. CDM Rule Book. Baker & McKenzie's Global Climate Change Practice, August 2008 <www.cdmrulebook.org/Page/home>.

Ball, J., 2006. Waste management in developing countries: seven characteristics and seven principles. In: WasteCon 2006 Eighteenth Waste Management Conference and Exhibition, October 2006, Cape Town, South Africa.

Barth, J., Favoino, E., 2005. Composting biowaste: state of the art, trends, drivers in environmental policy. In: Proceedings of the 1st BOKU Waste Conference, Wien, pp. 131–141.

Blight, J., Mussane, I., 2007. Sustainability and recycling in poor communities: a case study in the Eastern Cape, South African. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 202–213.

Blight, G.E., Fourie, A.B., Novellla, P., Pieterse, T., 2003. 'Store and release' landfill covers in semi-arid climates: experiments in South Africa. In: Sardinia 2003 Ninth International Waste Management and Landfill Symposium, October 2003, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Bogner, J.E., Meadows, M., Czepiel, P., 1997. Fluxes of methane between landfills and the atmosphere, natural and engineered controls. Soil Use and Management 13, 268–277.

Bogner, J.E., Lee, C.A., Chanton, J., Spokas, K., 2004. Reducing greenhouse gas emissions through landfill gas recovery in South Africa. In: WasteCon 2004 Seventeenth Waste Management Conference and Exhibition, October 2004, Johannesburg, South Africa.

Cavallari, S., 2005. A simple approach for biogas production estimation. In: Sardinia 2005 Tenth International Waste Management and Landfill Symposium, October 2005, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Coetzee, J.A., Haider, M.S., Hall, C.J., Keraan, S., 2007. Impacts on solid waste disposal resulting from the implementation of integrated waste management polices and plans: City of Cape Town, South Africa. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Cointreau, S., 2006. Occupational and Environmental Health Issues of Solid Waste Management: Special Emphasis on Middle- and Lower-Income Countries. The World Bank Group, Urban Papers, July 2006. <www.worldbank.com>.

Collivignarelli, C., Vaccari, M., 2007. Solutions to improve the MSW collection in Louga City, Senegal. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Collivignarelli, C., Mazzu, A., Sorlini, S., 2007a. Appropriate technologies for energy recovery from biomass in Africa. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Collivignarelli, C., Sorlini, S., Cavallari, S., Vaccari, M., 2007b. Waste management and recovery in developing countries. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 33–40.

Corti, A., Lombardi, L., Pecorini, I., Frassinetti, L., 2007. Diffused landfill gas emission monitoring in non-hazardous waste landfills: study cases. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Cossu, R., Piovesan, E., 2007. Modern role of landfill as geological sink for carbon and other elements. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Couth, R., Trois, C., 2009a. Comparison of waste management activities across Africa with respect to carbon emissions. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Couth, R., Trois, C., 2009b. Calculation of carbon emissions from waste management activities across Africa and potential for reduction. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Crawford, G., 2008. Landfill Gas Capture and Utilisation Projects. Presentation from April 9, 2008, BBL on Veolia Environmental Services and Landfill Gas Recovery Projects. <http://siteresources.worldbank.org/INTUWM/Resources/340232-1208964677407/Veolia_4-9-08.pdf>.

DEFRA, 2009. Landfill bans and restrictions in the EU and US: research project final report SID5. Department of Food and Rural Affairs (DEFRA), August 2009. <http://randd.defra.gov.uk/Document.aspx?Document=WR1202_8231_FRP.pdf>.

Diaz, L.F., Savage, G.M., Eggerth, L.L., 2007. The management of solid wastes in economically developing countries. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 17–29.

DWAF (Department of Water Affairs and Forestry), 2001. The development of a sanitation policy and practice in South Africa. <http://www.dwaf.gov.za/>.

Ecosystem Marketplace, 2008. Offsetting Emissions: A Business Brief on the Voluntary Carbon Market. Ecosystem Marketplace and Business for Social Responsibility, second ed., February 2008. <http://www.ecosystemmarketplace.com/>.

Esakku, S., Swaminathan, A., Karthikeyan, O.P., Kurian, J., Palanivelu, K., 2007. Municipal solid waste management in Chennai, India. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Esan, O., Wenborn, M., 2007. Private sector participation in SWM in developing and low-income countries – a case study of Ethiopia. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 127–137.

Espinoza, R.D., Morris, J.W.F., Bier, J., 2007. Valuing risk in landfill gas project development including emissions reduction credits: a real options perspective. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

European Union, 2006. Review of the EU Sustainable Development Strategy (EU SDS). DOC 10917/06. 26 June 2006.

Farouque, A.B., Mahmood, T., 2007. Gujrat sanitation program. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Ferreira, J.A., Ritter, E., Franco, R.S., Valle, S.S., 2007. Solid waste management in small municipalities. The case history of Pira? (RJ), Brazil. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Freeman, S.A., Mgingqizana, N., 2002. Negotiating the Public Private Partnership maze – lessons learnt in setting up recycling centres in Durban. In: WasteCon 2002, Sixteenth Waste Management Conference and Exhibition, October 2002, Durban, South Africa.

Fricke, K., Santen, H., Bidlingmaier, W., 2007. Biotechnological processes for solving waste management problems in economically less developed countries. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 41–56.

Godfrey, L., Nahman, A., 2007. Are developing countries ready for first world waste policy instruments? In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Gregory, R.G., Rosevear, 2005. GasSim 2: landfill gas management quantified. In: Sardinia 2005 Tenth International Waste Management and Landfill Symposium, October 2005, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Gregory, R.G., Attenborough, G.M., Hall, D.H., Deed, C., 2003. The validation and development of an integrated landfill gas risk assessment model: GasSim. In: Sardinia 2003 Ninth International Waste Management and Landfill Symposium, October 2003, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Groengroeft, A., Gebert, J., Berger, K., Melchior, S., 2009. Optimisation of landfill cover properties with regard to water balance and methane oxidation. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

GTZ, 2006. Economic aspects of informal sector activities in solid waste management, GTZ Report Reference number 81084644, GTZ, November 2006.

Habtetsion, S., Ghirmay, B., Tesfu, I., 2004. Potential of Electricity Generation from Land Filling in Eritrea. Working Paper No. 315, AFREPREN/FWD, Nairobi, 2004. <http://www.afrepren.org/Pubs/wpp1.htm>.

Huber-Humer, M., Lechner, P., 2009. Biocover construction and monitoring – implementation criteria and processes. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Hunger, G., Stretz, J., 2006. 'Proof of Service' – an innovative multifunctional tool for sustainable solid waste management strategies in developing countries. In: WasteCon 2006, Eighteenth Waste Management Conference and Exhibition, October 2006, Cape Town, South Africa.

ICBE, 2008. Calculating greenhouse gases. International Carbon Bank & Exchange (ICBE). <http://www.icbe.com/emissions/calculate.asp>.

Jean-Baptiste, N., Bidlingmaier, W., 2007. People and waste: understanding the real value of waste in Morelos, Mexico. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Jeon, E.J., Bae, S.J., Lee, D.H., Seo, D.C., Chun, S.K., Lee, H., Kim, J.Y., 2007. Methane generation potential and biodegradability of MSW components. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Kjeldsen, P., Scheutz, C., Fredenslund, A.M., Pedersen, G.B., 2009. Mitigating methane emissions from landfills using biocovers – lessons learned and future challenges. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Lee, C., Bogner, J., Aalders, E., 2005. Landfill gas recovery: the low hanging fruit for carbon credits trading in developing countries. In: Sardinia 2005 Tenth International Waste Management and Landfill Symposium, October 2005, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Lee, C., Bogner, J., Toefy, A., 2007. Landfill gas CDM projects: current trends and future opportunities for developing countries. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Liebenberg, C.J., 2007. Public Private Partnership solutions to waste management in developing countries in Africa. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Linzner, R., Mostbauer, P., 2005. Composting and its impact on climate change with regard to process engineering and compost application – a case study in Vienna. In: Sardinia 2005 Tenth International Waste Management and Landfill Symposium, October 2005, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Lopes, R.F., Shan Muganantha, S., Lippett, R., Keir, A., Mellos, R., Hoornweg, D., 2007. Municipal solid waste management in the Latin American and Caribbean regions: trends and opportunities for improvement. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Maciel, F.J., Jucá, J.F.T., 2009. Bioenergy from a municipal solid waste landfill in Brazil. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Matete, N., Trois, C., 2008. Towards Zero Waste in emerging countries – a South African Experience. Waste Management 28 (8), 1480–1492.

McKinnon, C., 2009. South Africa's bests practice methodology on refuse collection and cleansing in informal settlement areas. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Moller, J., 2007. Greenhouse gas balance of different waste management strategy. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Morris, J.W.F., Scharff, H., 2009. Critical elements on defining landfill sustainability and completion criteria. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Muniafa, M., Otiato, E., 2008. Solid waste management in Nairobi, Kenya. A case for emerging economics. In: WasteCon 2008, Nineteenth Waste Management Conference and Exhibition, October 2008, Cape Town, South Africa.

NSW, Department of Environment and Conservation, 2005. Benefits of Recycling, May 2005. ISBN 1 74137 311 5. <http://www2.epa.nsw.gov.au/resources/2005139_gov_benefitrecyrpt.pdf>.

Otieno, F.A.O., Taiwo, O., 2007. Current state of urban solid waste management in some cities in Africa. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Paul, J.G., Flora, R.J., Buquiran, M., Palma, J.D., Cadiz, L., 2007a. Composting as a suited tool to enhance waste management in rural areas in the Philippines. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Paul, J.G., Jaque, D., Kintanar, R., Sipalan, J.C., Gallo, R., 2007b. 'End-of-the-Pipe' material recovery to reduce waste disposal and to motivate the informal sector to participate in site improvements at the Calajunan dumpsite in Iloilo city, Panay, Philippines. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Rettenberger, G., 2009. Recovery of landfill gas under conditions of landfills in developing countries. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Ritzkowski, M., Heyer, K.U., Stegmann, R., 2003. In situ aeration of old landfills: carbon balances, temperatures and settlements. In: Sardinia 2003 Ninth International Waste Management and Landfill Symposium, October 2003, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Sauramba, J.B.O.J., 2002. Waste management in Namibian rural communities. In: WasteCon 2002, Sixteenth Waste Management Conference and Exhibition, October 2002, Durban, South Africa.

Segosede, E.M., 2008. Privatisation of waste management services in Gaborone: Panacea or one side of the same coin. In: WasteCon 2008, Nineteenth Waste Management Conference and Exhibition October 2008, Durban, South Africa.

Sherif, H.O., 2007. Solid waste management in Egypt: current situation and future prospects. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 105–116.

Spies, S., Florisbela dos Santos, A.L., Wehenpohl, G., 2007. Informal sector activities – obstacles and examples for its integration in municipal solid waste management. In: Diaz, L.F., Eggerth, L.L., Savage, G.M. (Eds.), Managing Solid Wastes in Developing Countries. CISA Publisher, Padova, Italy, pp. 159–168.

Spokas, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Moreau-Le Golvan, Y., Hebe, I., 2005. Methane mass balance at three landfill sites: what is the efficiency of capture by gas collection systems? Waste Management 26, 516–525.

Spokas, K., Bogner, J., Chanton, J., Franco, G., 2009. Developing a new field-validated methodology for landfill methane emissions in California. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Stotko, O., Trois, C., 2006. Overview of waste minimization strategies in Cape Town and Johannesburg. In: WasteCon 2006. Eighteenth Waste Management Conference and Exhibition, October 2006, Cape Town, South Africa.

Strachan, L.J., Pass, J. 2009. Where from and where to: 15 years of land filling in South Africa. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Straka, F., Lacek, P., Kuncarva, M., 2009. Landfill gas mitigation using biofilters. In: Sardinia Twelfth International Waste Management and Landfill Symposium, October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Tesink, J.G., Kabungo, M.K., 2006. The Lusaka waste management project, an attempt to implement sustainable waste management in Zambia. In: WasteCon 2006, Eighteenth Waste Management Conference and Exhibition. October 2006, Cape Town, South Africa.

UK–Environment Agency, 2004. Guidance on the management of landfill gas. September 2004. <http://www.environment-agency.gov.uk/static/documents/Business/lf_tgn_03_888494.pdf>.

United Nations, 1992. Rio Earth Summit 1992: United Nations Convention on Climate Change. United Nations Conference in Environment and Development (UNCED), June 1992. <http://unfccc.int/essential_background/convention/items/2627.php>.

United Nations, 1997. Kyoto Protocol 1997, United Nations Convention on Climate Change (UNFCCC). UNFCCC, 11 December 1997. <http://unfccc.int/kyoto_protocol/items/2830.php>.

United Nations, 2004a. AM0010: approved baseline methodology 'Landfill gas capture and electricity generation projects where landfill gas capture is not mandated by law'. UNFCCC, July 2004. <http://cdm.unfccc.int/UserManagement/FileStorage/CDMWF_AM_675903718>.

United Nations, 2004b. ACM001 Approved consolidated baseline methodology 'Consolidated baseline methodology for landfill gas project activities'. UNFCCC, September 2004. <http://cdm.unfccc.int/UserManagement/FileStorage/eb15repan1.pdf>.

United Nations, 2006. List of Sectoral Scope. UNFCCC, CDM-ACCR-06 Version 4. http://cdm.unfccc.int/DOE/scopelst.pdf.

United Nations Framework Convention on Climate Change (UNFCCC), 2009. Report of the individual review of the annual submission of the European Community submitted in 2009. Document code: FCCC/ARR/2009/EC. <http://unfccc.int/documentation/documents>.

Van Vossen, W.J., Heyer, K.U., Woelders, H., 2009. Feasibility study of sustainable emission reduction as the existing landfills Wieringermeer and Kragge in The Netherlands: processes in the waste body and design and costs of enhancing measures (infiltration/aeration). In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Volegeli, Y., Lohri, C., Kassenga, G., Baier, U., Zurgbrügg, C., 2009. Technical and biological performance of the Arti compact biogas plant for kitchen waste – case study from Tanzania. In: Sardinia 2009 Twelfth International Waste Management and Landfill Symposium October 2009, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

Wagner, P., Bidlingmaier, W., McKey, T., 2007. Implementation of environmental capacity building processes – problems and strategies based on experiences in South Africa. Managing solid wastes in developing countries, pp. 217–221. ISBN 978-88-6265-000-7.

WCED (World Commission on Environment and Development),1987. Brundtland Report: Our Common Future. Oxford University Press; 1987. <http://www.ace.mmu.ac.uk/esd/Action/Brundtland_Report.html>.

Wehenpohl, G., Kolb, M., 2007. The economical impact of the informal sector in solid waste management in developing countries. In: Sardinia 2007 Eleventh International Waste Management and Landfill Symposium, October 2007, Santa Margherita di Pula, Cagliari, Sardinia, Italy.

World Bank, 2007a. Assessment of carbon finance deliveries: final report. SCS Engineers, 2007.

World Bank, 2007b. Comparison of forecast and reported methane recovery rates at selected landfills in developing countries. SGS Engineers, 2007.

WRATE, 2009. Waste and Resources Assessment Tool for the Environment (WRATE). UK Environment Agency 2009. <http://lca.jrc.ec.europa.eu/lcainfohub/tool2.vm?tid=197>.