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Cost effective waste management through composting in Africa

R. Couth, C. Trois *

CRECHE, Centre for Environmental, Coastal and Hydrological Engineering, Civil Engineering Programme, School of Engineering, University of KwaZulu-Natal, Durban 4041, South Africa

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ABSTRACT

Greenhouse gas (GHG) emissions per person from urban waste management activities are greater in sub-Saharan African countries than in other developing countries, and are increasing as the population becomes more urbanised. Waste from urban areas across Africa is essentially dumped on the ground and there is little control over the resulting gas emissions. The clean development mechanism (CDM), from the 1997 Kyoto Protocol has been the vehicle to initiate projects to control GHG emissions in Africa. However, very few of these projects have been implemented and properly registered. A much more efficient and cost effective way to control GHG emissions from waste is to stabilise the waste via composting and to use the composted material as a soil improver/organic fertiliser or as a component of growing media. Compost can be produced by open windrow or in-vessel composting plants. This paper shows that passively aerated open windrows constitute an appropriate low-cost option for African countries. However, to provide an usable compost material it is recommended that waste is processed through a materials recovery facility (MRF) before being composted. The paper demonstrates that material and biological treatment (MBT) are viable in Africa where they are funded, e.g. CDM. However, they are unlikely to be instigated unless there is a replacement to the Kyoto Protocol, which ceases for Registration in December 2012.

1. Introduction

This paper aims to assess the economic advantages of options for municipal solid waste (MSW) composting against landfill gas recovery in Africa. The paper is part of a PhD study to assess greenhouse gas (GHG) emissions from waste management in Africa and evaluate measures to reduce the rate of their increase. This study is part of a larger research project on Zero Waste and Waste Management Strategies towards the effective reduction of carbon emissions in the atmosphere from developing countries conducted by the University of KwaZulu-Natal since 2002.

Africa is the world's second largest and most-populous continent after Asia. With around one billion people in 61 territories, it accounts for almost 15% of the world's population, of which approximately 60% is rural and 40% urban. The rural growth rate is reported as static (0%) with an increasing urban population growth rate of 6.6% per annum (Earthtrends, 2008). Rural waste is traditionally managed through reuse, recycling and composting. Urban waste is primarily disposed in landfills generating methane (CH_4) gas, which is 21 times more potent as a GHG than the natural carbon dioxide (CO_2) produced through composting the biogenic wastes. The World Trade Organisation designated 96% of the countries in Africa as having a low Human Development Index (HDI); 68% are designated by the United Nations (UNs) as 'least developed countries' (LDCs), and all of the countries in sub-Saharan Africa are designated under the Kyoto Protocol as Non-Annex 1 parties (developing countries) (United Nations, 1997; Couth and Trois, 2009a). In most of the African countries, little of the gross domestic product (GDP) is allocated to waste management and therefore low cost, low technology solutions need to be provided.

In 2002, KwaZulu-Natal University initiated the first mechanical biological pre-treatment of municipal solid waste in South Africa in collaboration with the eThekwini Municipality, in the city of Durban. The Durban pilot project involved waste pre-treatment in passively aerated windrows, using the Dome Aeration Technology (DAT) (Parr et al., 1999; Trois et al., 2007) and prolonged passive aeration in shallow landfills using the Pre-treatment Aeration and Flushing (PAF) model (Cossu et al., 2002). These trials have demonstrated that municipal solid waste (MSW) can be composted to reduce the biogenic carbon content and relative GHG emissions (Trois et al., 2007; Trois and Simelane, 2010). However, the cost benefits of composting over landfill disposal and opportunities opened by the clean development mechanism (CDM) have not been fully developed and quantified.

This paper provides an introduction into GHG emissions and CDM MSW-composting projects in Africa, together with an explanation of MSW composting and the DAT process. It then reviews end-of-waste implications for MSW compost before undertaking

* Corresponding author. Tel.: +27 31 260 3065/55; fax: +27 31 260 1411.
E-mail address: troisc@ukzn.ac.za (C. Trois).

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a cost comparison of MSW composting options against landfill gas recovery options. Conclusions are finally presented on MSW composting in Africa and related CDM opportunities.

2. Waste composting and CDM opportunities in Africa

2.1. Introduction

The total carbon content of MSW can be divided into two main categories – biogenic carbon and fossil carbon (Moller, 2007). Biogenic carbon is mainly found in biodegradable fractions, such as organic kitchen waste and cardboard (bio-waste), and paper. Fossil carbon is, in general, non-degradable and is found in plastic and synthetic fabric. The remaining dry recyclable material in MSW is primarily metal and glass which may be recycled and contain very little or no carbon, respectively. MSW also contains other inert materials including aggregates and soils. The biogenic waste can be aerobically composted and/or anaerobically digested and is referred to in this paper as 'wet' waste whilst the remaining recyclable material is referred to as 'dry' waste. The fossil carbon can be disposed in landfills, which are considered as carbon "sinks" where the slowly degradable organic fractions, such as lignin and hemicellulose, remain stable in the landfill for hundreds of years. The potential GHG emissions from this type of landfill are minimal, as detailed in Couth et al. (2011).

The anaerobic degradation of biogenic waste in landfills is the main source of GHG, in the form of CO_2 and CH_4. Consequently, if mechanical biological treatment (MBT) of waste can take place prior to disposal, GHG emissions and landfill costs can be significantly reduced.

The main advantages of composting CDM projects over landfill gas CDM projects are:

1. Economical benefits: greater CDM income from the avoidance of methane emissions.
2. Environmental: the waste is not landfilled therefore avoiding the adverse environmental impact from, e.g. land contamination; odour; potential hazardous air emissions; greenhouse gas (GHG) emissions; leachate production and potential groundwater pollution; visual intrusion; litter nuisance.
3. Social benefits: More employment opportunities with improved working conditions for waste pickers; an increase in the number of jobs for the local community; and reduced health risks to the neighbouring communities.

2.2. GHG emissions and CDM opportunities in Africa

UNFCCC data show that, of the 50 countries in sub-Saharan Africa, all but five (Botswana, Mauritius, Reunion, Seychelles and South Africa) had emissions below the 2.256 tCO_2 per capita threshold for controlling global warming (UNFCCC October, 2005). A further four had emissions between 1 and 2tCO_2 per capita, with 42 sub-Saharan countries below 1tCO_2 per capita. South Africa is an exception, at 9.1927tCO_2 per capita in 2004, double the world average of 4.56tCO_2 per capita. The mean for sub-Saharan countries in 2004 was 1.0215tCO_2 per capita, but with South Africa excluded, the mean was 0.8547tCO_2 per capita, just over a third of the 2.256 tCO_2 threshold (Couth and Trois, 2009b). The lowest 2004 return was for Chad, at 0.0138 tCO_2 per capita. However, the source data for these figures is very questionable with significant variations between countries. The sub-Saharan countries recorded a massive increase in CO_2 emissions between 1994 and 2004, between 222% and 307% for UNSD (United Nations Statistics Division) and CDIAC (Carbon Dioxide Information Analysis Centre) figures respectively. The UN Commission on Sustainable Development (CSD) indicators relevant to waste management and carbon emissions include: CO_2 emissions, emissions of greenhouse gases, generation of waste, treatment and disposal. These indicators show that 6.8% of the GHG emissions for Africa are from waste, greater than the average of 4.2% for Non-Annex I parties (Couth and Trois, 2009b). The GHG emissions from waste will increase as the urban population grows and seeks the living standards of developed countries.

This study to date has concluded that the average urban MSW waste arisings in Africa are typically around 230 kg/hd/year of which the organic content is around 56% (Couth and Trois, 2010). The main GHG emission from waste management is CH_4 resulting from the anaerobic digestion (AD) of biogenic waste in landfills. With an urban population of over 0.4 billion, and a global warming potential (GWP) of CH_4 of 21 compared with CO_2, the GHG emissions from landfill gas for Africa equate to around 66 $MtCO_{2e}$/year. The global warming impact of landfill may be reduced by capturing and combusting the landfill gas. However, landfill gas management systems in Africa are only effective at collecting around 50% of the generated gas (World Bank, 2007). If all of the landfills in Africa were managed with landfill gas extraction systems, which continuously operated to capture, and combust 50% of the gas emissions, then the GHG emissions from landfill gas could be reduced to around 33 $MtCO_{2e}$/year. In comparison, composting schemes would effectively increase the capture rate to 100% by pre-treating the biogenic waste prior to final disposal.

The UNFCCC CDM composting methodology is AM0025 (UNFCCC AM0025, 2008), and the tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site is Annex 10 from EB 41 (Executive Board 41) (UNFCCC Annex 10, 2008). Annex 10 is a methodological tool that calculates baseline emissions (tCO_{2e}) of methane from waste that would in the absence of the project activity be disposed at landfill sites. Emission reductions are calculated with a first order decay model. AM0025 is an extensive methodology that applies to aerobic composting, gasification, anaerobic digestion, mechanical biological treatment producing a refuse derived fuel (RDF), and incineration producing energy from waste (EfW). CERs are gained from the methane emission reductions from landfilled waste, and potentially from carbon dioxide emission reductions from the combustion of fossil fuel, which would have been used to manufacture the replacement fertiliser. The GHGs in the baseline and project activity for landfill and composting are CH_4, and N_2O respectively. Landfills can emit small amounts of N_2O but these are not normally included. For N_2O emissions from composting, AM0025 has a default value of 0.043 kg-N_2O/t-compost.

The first example of CDM applied to waste composting in Africa is the Cairo CDM project, which involves mechanical and manual sorting of dry waste, followed by the shredding and turned windrow composting of the wet waste (UNFCCC PDD, 2007). The windrow composting process consists of two phases, which last 73 days (>10 weeks):

- Fermentation phase, which lasts 28 days with windrows being turned twice a week by a mobile machine. Water is sprayed over the windrows. The carbon-to-nitrogen ratio (C:N) is monitored and when this is too low agricultural waste is added; while if the C:N ratio is too high cow manure is added;
- Maturation phase that lasts 45 days, during which the windrows are turned on average once per week, depending on feedback from the process control. Toxicity and heavy metals checks are also made.

CERs are calculated for methane emissions saved from landfilling, less fuel, electric production and methane emissions from composting activity. Some 82% of the compost produced is being sold and the project will generate 76,652 CERs per year. Further similar CDM projects are being initiated in North Africa, e.g. Khartoum, Sudan (Tawfig et al., 2009).

The second CDM composting project in Lagos (UNFCCC PDD, 2009), involves the shredding of unloaded waste to <7 cm followed by windrow composting. A trench is cut in the windrow for addition of water to optimising the moisture content in the shredded material. During the moisture-supplementing step, dry and wet inoculants are also added to increase the rate of maturation. The inoculants are a proprietary mix of chemicals that accelerate degradation of organic waste and speed up the decay of oily and greasy waste that impede organic decay. It is estimated that the project will generate 144,579 CERs per year.

2.3. Waste composting

Compost is defined as the solid particulate material, which has been sanitised and stabilised as the result of composting (Haug, 1993; Joint Research Centre, 2008). Composting is a process of controlled decomposition of biodegradable materials under managed conditions, which are aerobic and which allow the development of temperatures suitable for the establishment of thermophilic bacteria (above 45 °C) as a result of biologically produced heat. If high temperatures are maintained for a sufficiently long time (60–70 °C), pathogenic micro-organisms are killed along with the weed seed, and the material can be considered hygienically safe for land use (Trois et al., 2007). Compost is an organic stable material with a content called humus that is dark brown or black and has a soil-like, earthy smell. The positive environmental benefits of composting biogenic waste include:

- The use of compost as an organic fertiliser to replace the use of mineral fertilisers, avoiding the environmental stresses of fertiliser production, e.g. the impacts of phosphate extraction;
- Reduction in greenhouse gas emissions (CH_4 and energy related emissions); and
- The use of compost over longer periods of time and a lower use of mineral fertilisers reduces nitrate leaching.

The process technologies of composting are very diverse. The principal techniques used in MSW composting are turned windrow approaches, open aerated systems, and contained systems (vertical and horizontal reactors and agitated systems) (Bardos, 2004).

Composting consists of two stages, active composting followed by maturation. When the windrow is formed microorganisms consume oxygen (aerobic decomposition). Aeration can be provided by large pore spaces that promote air movement through the windrow (DAT); by mechanical agitation (turning) to add oxygen and replenish pore space within the settled medium; or by blowing or sucking air. The temperature increases due to microbial activity to 40–60 °C. Subsequently as the aerobic decomposition slows the temperature drops off. When the aerobic decomposition has slowed the curing (maturation) phase has begun, and as the temperature drops to that of ambient air, the composting is complete.

The dominant process variables are aeration, temperature and moisture. It can be difficult to sufficiently aerate the composting mass to control temperatures and so maximise processing rates, without over-drying it. For biogenic waste composting to be successful (Haug, 1993; Trois et al., 2007):

- the oxygen concentration should be maintained above 15%;
- the temperature in the composting process should be 50% to 60 °C;
- the moisture content should be 50% to 55%;
- the carbon to nitrogen (C:N) ratio should be between 25:1 and 30:1;
- the pH should be between 6.5 and 8;
- there should be a small particle size to allow greater surface area for aeration; and
- must reduce the Respiration Index of the waste to less than 5 $gO_{2/}kgDM$ before disposal.

Biogenic waste composting in windrows, and in-vessel compostors (IVCs) in developed countries, is designed to control oxygen, temperature and moisture content. C and N are the two most important elements in the composting process, and one or the other is normally the limiting factor. C serves as the energy source and N is critical for microbial population growth.

Crop residues and animal manure have traditionally been composted in long rows, referred to as windrows. These rows are generally turned to improve porosity and oxygen content, mix in or remove moisture, and redistribute cooler and hotter portions of the pile. In-vessel composters (IVCs) are an alternative to windrow composting and generally consist of metal tanks or concrete bunkers in which airflow and temperature can be more readily controlled, using the principles of a "bioreactor" (e.g. VCU, http://www.vcutechnology.com). Generally the air circulation is metered via buried tubes that allow fresh air to be injected under pressure, with the exhaust being extracted through a biofilter, and temperature and moisture conditions monitored using probes in the mass to allow maintenance of optimum aerobic decomposition conditions. IVCs are not considered applicable in Africa due to reasons of cost, technology and maintenance.

Windrows for MSW composting are typically 1.5–3 m high and 3–6 m wide, but the cross-sectional dimensions vary with feedstock and turning equipment (Richard, 2000b). Pile size may be increased in extremely cold weather or when decomposition slows as compost matures. Mechanically turning the pile releases heat and moisture and can temporarily increase the porosity. Agitation can also help break up clumps of material and thereby increase oxygen transfer. Management of convection and diffusion through pile size and turning frequency can be a cost-effective strategy, although decomposition is generally not as rapid as with forced aeration systems. The length of time that the bio-waste is composted depends on the feedstock, the windrow composting process, and the output specification. Windrow composting with mechanical turning typically ranges from 4 to 6 weeks and is then matured for a further 6 to 12 weeks.

Gaseous emissions from the composting process include carbon dioxide (CO_2), water vapour, and in smaller quantities ammonia (NH_3), volatile organic compounds (VOCs), bioaerosols (fungi, bacteria, actinomycetes, endotoxins, mycotoxins) and particulates. In theory, composting as an aerobic process should not generate CH_4. In practice, however, and depending on the type of composting process and its management, the oxygen supply and the aerobic conditions during the biological degradation may be suboptimal. The lack of oxygen may then lead to anaerobic processes and to emissions of CH_4. The proportion of the carbon content of the input material that is transformed into CH_4 emissions varies widely, depending on the type of input materials and the processes, but can be between 0.01% and 2.4% of the original carbon according to ADEME (2005). A typical value found for CH_4 emissions from household waste composting would be 0.04 kg CO_2e per kg of dry matter of the input material. According to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, (IPCC, 1996), CO_2 from organic waste handling and decay should not be included in greenhouse gas inventories. The reason is that organic material derived from biomass sources, which are grown on an annual basis, is the primary source of CO_2 released from such waste and these would have occurred naturally. Greenhouse gas emissions may be either biogenic or anthropogenic in origin. According to international convention, only greenhouse gas emissions resulting from anthropogenic sources (derived from human activity) are considered in emissions calculations. For the composting of bio-waste, the N_2O emissions have been found to be in the range of 0.002 to 0.05 kg CO_2e per kg of input dry matter (typical value: 0.02 kg CO_2e). For household waste, the range is 0.005 to 0.125 kg CO_2e per kg of input dry matter (typical value 0.1 kg CO_2e) (Joint Research Centre, 2008).

Critical elements to waste composting in Developed Annex 1 countries are collection, contaminant separation, sizing and mixing, and biological decomposition (Richard, 2000a), together with the compost output specification (BSI PAS100, (WRAP, 2007)). Size reduction increases the surface area of the organic wastes, enhancing opportunities for biological activity, while mixing ensures that nutrients, moisture and oxygen are adequate throughout the material. All of the African projects considered in the cost benefit comparison in this paper assume that the particle size is controlled by shredding prior to composting.

It should be noted that anaerobic digestion (AD) facilities have advantages over windrow composting facilities in that they do not require the same area of land take and they produce CH_4, which may be used as renewable energy. However, they are more efficient with a homogeneous feedstock (kitchen waste rather than MSW); they require a greater capital investment; they require technical expertise to operate and maintain; and they produce a digestate, which needs to be processed or disposed. Consequently AD is considered less favourable for waste treatment in Africa than windrow composting.

2.4. Dome composting

In the first application of MBT of waste in South Africa, the Dome Aeration Technology (DAT) was selected as an appropriate low-cost, zero/low energy solution and modified for the specific prevailing conditions experienced in Durban (Trois et al., 2005, 2007). The DAT system involves the creation of large airspaces within the windrow using steel mesh structures, called domes and channels. The domes and channels are designed to encourage air movement through the windrow for oxygen and temperature control. From the perspective of the windrow cross section, the domes are placed vertically in the centre of the pile, extending throughout the windrow height, and two channels are placed horizontally at the base, on opposite sides of the pile, extending from the edge towards (but not reaching) the centre. The domes and channels are placed in a staggered configuration relative to each other. A chimney extends from the top of the domes, and a layer of inert matter covers the composting material. No turning is required and the windrow is passively aerated through the channels while hot exhaust gasses are vented through the dome chimneys (Fig. 1).

Research into the DAT system of waste treatment was initially conducted at the landfill site of Plauen in Germany by the University of Dresden (Parr et al., 1999). The system has been successfully implemented at full scale at the Cottbus Landfill Site, which received approximately 50,000 tons of refuse annually (Mollekopf et al., 2002). The windrows used at Cottbus were 11 m wide and 3 m high, including 0.5 m of cover material. Although the length of the windrow is not specified, generally 8 domes are used (approximately 40 m long). The limiting value of 250 mg/l for TOC, as stipulated by the German regulations, was met within 6 months of composting.

Five windrows were constructed as part of the Durban pilot project, with the following characteristics:

1. Windrow 1: 50% MSW and structural waste (1:1), 50% pine bark, 3 domes;
2. Windrows 2 and 3: MSW, structural waste, pine bark (2:1:1), 3 domes; and
3. Windrows 3 and 4: MSW, structural waste, pine bark (2:1:1), 5 domes with irrigation.

The input material was typical MSW that is disposed daily at the Bisasar landfill site from ROTOPRESS trucks, that were preferred to other general collection vehicles because they comminute the waste on route, delivering well mixed and partially shredded material. The MSW was mixed with structural material (woody waste) on a tipping truck (ADT) and loading on the truck was done with an excavator. Further mixing, crushing and wetting were performed during the placement of the material on site. A layer of pine bark was used to insulate the pile during composting.

Waste was composted for a maximum of 16–20 weeks, with interim sampling after 8 weeks. Temperatures, oxygen levels, quality and quantity of the exhaust gasses and moisture content were monitored throughout the process. Temperatures peaked at around 70 °C for around 5–10 days at the start of the trials, falling to ambient temperature in 80 days. The moisture content values ranged between 0% and 30% after 97 days. The oxygen remained above 15% throughout the trials. At the end of the trail some 50% of the theoretical biodegradable content had been removed. Approximately 50% of the organic carbon is biogenic with the remaining 50% more slowly degradable fossil carbon (wood, pine bark, mixed paper). This figure for carbon reduction is similar to a comparative study carried where the percentage reduction in the BOD_5 was 43.6% after 8 weeks of composting (Trois et al., 2007). It is also interesting to compare the DAT composting performance against static windrow composting of screened MSW with forced aeration (Chackiath and Couth, 2009). The Welsh aerated static windrow process achieved a 46% reduction in BM100 (Biochemical Methane Potential 100-day) by the end of week 2, increasing to 67% by the end of week 4, with no further reduction in the 6 week composting trail (Fig. 2). The composting process and carbon removal is quicker with forced aeration in the cooler climate than static DAT aeration.

The advantages of covering the windrows with pine bark in the Durban trials were:

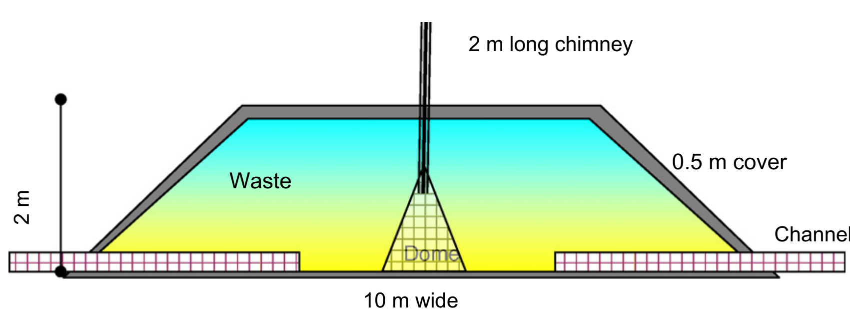

Fig. 1. Schematic cross-section of a typical DAT windrow (Trois et al., 2007).

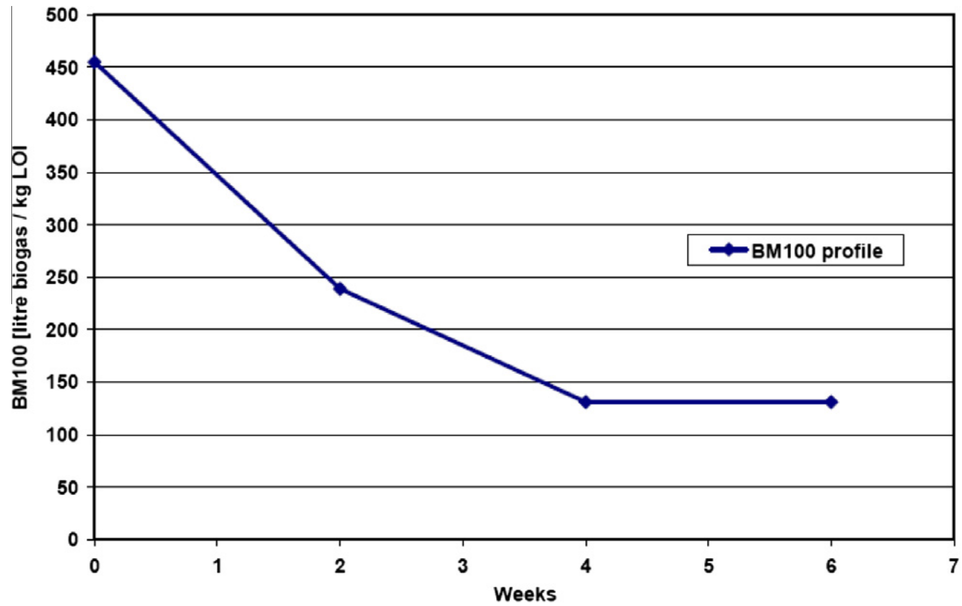

Fig. 2. BM100 tests for fine samples.

- minimization of emissions such as odour, and potential harmful gaseous substances and windblown litter;
- control of emissions and diffusive emission;
- reduced risk of animal or bird transfer of disease;
- high composting temperatures, increasing the composting rate; and
- insulation, i.e. protection against drying, wetting, cooling and heating by weather effects.

The Durban MBT trials have shown that DAT can be applied to waste in Africa, although it is less efficient in warmer climates as there is a lower temperature differential to encourage air movement. Factors such as low-cost infrastructure, low energy input, the potential for labour-intensive operations, job creation and poverty alleviation, and integration with daily landfill operations apply to windrow waste composting in Africa.

3. End-of-waste and cost comparison

3.1. End-of-waste

The European Union (EU) agreed on the Revised Waste Framework Directive (RWFD) (Directive 2008/98/EC) in November 2008 requiring member states to transpose into national legislation by 12 December 2010. The RWFD clarifies the waste hierarchy as prevention; prepare for reuse; recycling (including composting); other recovery (including energy recovery); and disposal. The RWFD defines end-of-waste as '*all the requirements that have to be fulfilled by a material derived from waste, and which ensure that the quality of the material is such that its use is not detrimental for human health or the environment*'. A certain waste may only cease to be a waste if the substance or object is commonly used for specific purposes; a market or demand exists for such a substance or object; the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and the use of the substance or object will not lead to overall adverse environmental or human health impacts. Compost from waste materials, which can be used as a soil improver/organic fertiliser and as a component of growing media, fulfils these end-of-waste requirements. Within the EU only compost, which is derived from food and green waste is likely to meet the BSI PAS100 specification (WRAP, 2007) and EU end-of-waste requirements. The BSI PAS 100 standard in only likely to be met from composting source segregated food waste and green waste. It cannot be met from composting MSW.

Unlike the EU, the majority of countries in Africa do not have standards for the application of aerobic compost and anaerobic digestate to land (for example South Africa does not currently have legislation controlling the quality of compost or digestate that can be applied to land). Source segregated collection of food and green waste is not cost effective in the majority of sub-Saharan countries, and therefore to be a practical alternative to landfill, compost produced from waste in Africa needs to be acceptable for use against a 'lower' standard than BSI PAS100. To maximise the quality of the compost that is applied to land, dry recyclable materials should be picked out of the residual waste and the residual waste should be shredded. This should maximise the biogenic content of the residual waste to be composted, and consequently the quality of the compost produced.

Composting of wastes should not cause impacts on human health. In 2001, the United Kingdom (UK) experienced an outbreak of foot and mouth disease. A potential cause was considered to be birds transporting meat waste from open MSW windrows which dropped in fields and was then eaten by cattle Because of this risk, the European Union (EU) introduced the Animal By-Products Regulations (ABPRs) in 2002 (Regulation 2002/1774/EC (2002)) to eradicate feed-borne crises such as Bovine Spongiform Encephalopathy (BSE, more commonly known as 'mad cow disease'), foot and mouth disease, swine fever and dioxin contamination. The ABPR ban the open windrow composting of MSW, and require housed windrows to have a maximum particle size of 40 cm, minimum temperature 60 °C, and minimum time at that temperature for 8 days. Regarding the temperature and time, windrows which are turned should have two sanitisation cycles each with 4 periods of at least 2 days at a temperature of more than 60 °C and 3 intermediate turning operations (Organic Research Agency Ltd., 2005). ABPR do not apply in Africa and transfer of animal diseases by open windrow composting remains a risk. This should be recognised and windrows managed (covered or with bird scaring) to minimize this risk. This was achieved in the University of KwaZulu-Natal composting trials by covering the windrows with pine bark (Trois et al., 2007; Trois and Simelane, 2010). Bird scaring equipment and birds of prey can also be used.

3.2. Cost comparison

The cost comparison between composting and managed landfill has been considered with and without CDM income for the following scenarios:

- MSW in static DAT windrows;
- Shredded MSW composting in turned windrows;
- Dry recyclable material recovery and shredded MSW composting in turned windrows (MBT – Mechanical Biological Treatment);
- Landfilling with gas flaring; and
- Landfilling with gas combusted to generate electricity.

The costs comparison is based upon the authors' knowledge of waste management and composting costs, and compost and landfill gas contracts in Africa. The cost comparison is qualitative, and whilst a quantitative cost model has been prepared, costs are not quoted as they are subjective.

Cost comparison between composting and landfilling options depends on quantity of MSW that needs to be disposed. This cost comparison applies to urban waste and assumes a population of 1,000,000 generating 230,000 tpa based on 230 kg/head/year. The assumption for the three composting scenarios is that the windrows are placed on a constructed hard-standing platform and the surface water runoff is managed as dirty water. The dirty water is discharged to sewer or managed through a reed bed. All of the composting scenarios are outdoors, and none are in-building due to the cost implications. The option 1: MSW in static DAT windrows are covered, e.g. with pine bark to control the risk from animal by-products. However, there remains a risk to animal by-products from options 2 and 3, but this may be controlled by bird scaring mechanisms. All three windrow options include for the monitoring of oxygen, temperature, moisture content and C:N. None of the composted options include for the forced aeration in the windrows.

For the cost benefit analysis, there are some assumptions, which have been applied to all scenarios:

(a) The CDM income is \$16/tCO2e per CER with 1.33 \$/€ exchange and 7R/\$ exchange;
(b) 10 year project life, assuming a 10 year CDM life is selected. A project will be more viable if the 3×7 year CDM life option is selected;
(c) 7 year life for plant and equipment;
(d) €100,000/ha land costs. This will be very variable in countries across Africa; and
(e) simple cost analysis without consideration of discounted cash flow.

The cost benefit analysis for the two landfill gas scenarios has been based on GasSim2 (Gregory and Rosevear, 2005) modelling of the above parameters using average African waste analysis (Couth and Trois, 2010). The cost benefit analysis for the three composting scenarios assumes continuous batches with 6 weeks composting followed by 11 weeks maturation. It is taken that the quality of compost from mechanically sorted and shredded MSW in turned windows is such that it has a marketable value and can be sold, whereas compost from MSW in static DAT windrows and shredded MSW in turned windows is such that it can be used as a fertiliser but does not have a marketable value. There is little difference in the land take for the three composting options. DAT windrows may be larger as their size is not restricted by turning equipment, however they have a lower overall density due to bulky material. The MBT option requires land for mechanical sorting and material storage but less area for composting. The composting projects provide emissions savings from energy used to manufacture compost and the MBT options also provides emissions savings from the energy used in manufacturing recycled materials. These secondary emission reductions are not included in CDM projects due to uncertainty in emission reductions.

The ranking from the cost benefit analysis is as follows:

1. Mechanically sorted and shredded MSW in turned windows MBT (Mechanical biological treatment);
2. MSW in static DAT windrows;
3. Shredded MSW in turned windows;
4. Landfilling with gas flaring; and
5. Landfilling with gas to electricity.

Considering the cost benefit analysis ranking in reverse order:

5. Landfilling with gas to electricity. Landfill gas to electricity CDM projects are only viable on the largest landfills in Africa. Landfill gas to electricity projects are not viable in Africa for waste from urban populations of 1,000,000 as the cost pe r 1 MW engine installed with a gas extraction system is over \$1,000,000, and the engines require expert maintenance. For landfill gas to electricity projects of this scale to be viable they require a renewable energy feed in tariff.
4. Landfilling with gas flaring. Landfill gas flaring projects should have a pay back period within a 7 year CDM term. Landfill gas flaring projects are not viable without CDM income. The GasSim2 analysis shows that approximately 1,800 m^3/h of gas is likely to be generated after 10 years of landfill disposal for 'typical' African waste. If the gas extraction system has 50% recovery efficiency, then this equates to 900 m^3/h of landfill gas or around 450 m^3/h of methane gas combusted as extracted landfill gas typically contains around 50% methane. Landfill gas systems will need continued operation and management to capture carbon for around 10 years after the landfill is closed. The landfill will continue to have a negative impact on the local and global environment for generations as biowaste degrades and releases leachate and landfill gas.
3. Shredded MSW in turned windows. The three composting options are considerably more favourable than landfill disposal and gas collection options as the waste is converted into a useable product and not left as a burden for future generations. Also, up to 100% of the biogenic carbon is captured within a relatively short period (4 months), whilst landfill gas schemes capture gas more slowly over a longer period (typically 10 years). It is assumed in the three composting options that composting is continuous and not a batch process; there is no income from the acceptance of waste and the avoided landfill costs; there is no difference in the composting times in the static dome and turned windrows; and all 3 composting options generate the same CERs. The pay back period for this scenario is within 2 years of the start of operation, allowing for up to 9 months for CER issuance (or 3 years from the start of construction investment, and at least 4 years from start of CDM project investment).
2. MSW in static DAT windrows. The cost for the static DAT windrow composting is slightly cheaper than the shredded MSW in turned windrow option although there is little difference in the capex costs. The cost benefit of the MSW in static DAT windrows option is very similar to the shredded MSW in turned windows option. It is questionable whether turning, air injection/exhaustion and moisture control equipment for windrow composting is technically viable in sub-Saharan Africa. How-

ever, if CDM or other funding is available, it would be recommended that the static piles are turned and the moisture is controlled. Turning will control oxygen, and moisture can be managed by monitoring the windrows and adding water to trenches before they are turned. The shredded and turned windrow system should therefore produce better compost from MSW than the DAT system.

1. Mechanically sorted and shredded MSW in turned windows (MBT (mechanical, biological treatment)). This is the most favourable option from the cost benefit analysis due to the income derived from dry recyclables and compost, although the value and security of this income is uncertain. The pay back period for this scenario should be within 3 years of start of operation, allowing for up to 9 months for CER issuance (or 4 years from the start of construction investment, and at least 5 years from start of CDM project investment). Depending on the markets for dry recyclables and compost, a mechanically sorted and shredded MSW in a turned window project could be viable without CDM income. However, a mechanically sorted and shredded MSW in a turned window project requires considerably more capital investment than just windrow composting, and such projects will therefore be dependent on the availability of funding which will be difficult in less stable African countries. Also, the viability is dependent on the markets for dry recyclables and compost, both of which can be volatile. This option does have the added advantage that the material sorting provides local employment, with the potential for over 100 jobs per scheme.

4. Conclusions

The cost benefit analysis shows that waste composting is beneficial over controlled landfilling, although uncontrolled dumping of waste as practiced across sub-Saharan Africa is cheaper in the short term. Of the composting options, it is attractive to have an upstream materials recovery facility (MRF) to remove dry recyclables from the waste, which will significantly improve the quality of the compost and will also provide local employment.

However, MBT and composting projects in Africa are unlikely to proceed without funding from Annex 1 developed countries through mechanisms similar to the CDM. The Kyoto Protocol concludes for the Validation and Registration of new projects in December 2012, so there is only very limited time to initiate new MBT composting projects across Africa. Also, the caution of funders and the bureaucracy of the CDM process mean that it is likely that very few new CDM projects will be initiated from hereon. The CDM is effectively dead to new projects.

Significant carbon emissions will continue to increase from landfills across Africa unless there is a mechanism to invest in waste recycling and composting projects. CoP15 (Conference of the Parties) in Copenhagen, December 2009 and CoP16 in Cancun in November 2010 both failed to agreed a replacement to the Kyoto Protocol, and it is considered that a replacement ought to be planned for CoP17 in Durban in November 2011.

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