Sustainable waste management in Africa through CDM projects

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Abstract

Only few Clean Development Mechanism (CDM) projects (traditionally focussed on landfill gas combustion) have been registered in Africa if compared to similar developing countries. The waste hierarchy adopted by many African countries clearly shows that waste recycling and composting projects are generally the most sustainable. This paper undertakes a sustainability assessment for practical waste treatment and disposal scenarios for Africa and makes recommendations for consideration. The appraisal in this paper demonstrates that mechanical biological treatment of waste becomes more financially attractive if established through the CDM process. Waste will continue to be dumped in Africa with increasing greenhouse gas emissions produced, unless industrialised countries (Annex 1) fund carbon emission reduction schemes through a replacement to the Kyoto Protocol. Such a replacement should calculate all of the direct and indirect carbon emission savings and seek to promote public–private partnerships through a concerted support of the informal sector.

1. Introduction

This paper assesses the sustainability of practical options for the management of urban municipal waste in Africa against disposal to landfill and the recovery of landfill gas. The paper is the conclusion of a study to quantify greenhouse gas (GHG) emissions from waste management activities in Africa and evaluate sustainable methods for controlling and reducing these emissions with the ultimate aim to propose to local authorities a philosophy for the sustainable management of these refuse. The study is part of a larger research project on Zero Waste and Waste Management Strategies for the effective reduction of carbon emissions in the atmosphere from developing countries (with focus on Africa), which has been conducted by the University of KwaZulu-Natal since 2002.

An extensive review of waste management practices across Africa (Couth and Trois, 2010) has concluded that the most sustainable way to manage waste in the majority of urban communities is to:

- remove dry recyclables by scavenging, through door to door collection, and/or a dirty materials recovery facility (MRF);
- compost the remaining biogenic waste in windrows, using the matured compost as a substitute fertilizer; and
- dispose reject fossil carbon (plastics, synthetic textiles, metals) and inert waste in sanitary landfills. If biogenic waste is removed the landfills should not require biogas extraction systems as the wastes will comprise mainly inert and fossil carbon wastes.

This waste management practice is in accordance with the internationally adopted waste hierarchy. It will require limited capital investment in comparison to complex and expensive waste treatment and landfill disposal systems which are typically used in developed countries. It will also require less technology and complexity.

The UNFCCC had sought to initiate GHG emission reductions through the Kyoto Protocol, which includes the CDM (United Nations, December 1997). The Kyoto Protocol has two objectives, firstly to support developed countries to reach their emission reduction targets through the mobilisation of more cost efficient reduction options in developing countries, and secondly to provide funding for sustainable development in developing countries (Couth and Trois, 2010). Round One of the Kyoto Protocol
concludes for the Validation and Registration of new projects in December 2012. There is less appetite for the Round Two period after December 2012–2017 or 2020, with no new initiatives planned to 2020. The caution of funders, the bureaucracy of the CDM process, and the limited market for Certified Emission Reductions (CERs) in Round Two of Kyoto make it less likely that many new CDM projects will be initiated across Africa, although many countries in Africa are Least Developed Countries (LDCs) and will be favoured for the purchase of CERs by the European Union Emissions Trading Scheme (EU-ETS). The CDM is dying and a new replacement mechanism is needed to control carbon emissions from waste management in all developing countries.

This paper seeks to quantify the cost, in terms of carbon reductions and social benefits, of different recycling and window composting options for municipal waste against disposal in landfills (with or without landfill gas and energy recovery systems). Following this introduction, the paper quantifies the emission reduction benefits of recycling wastes and composting biogenic wastes. The paper summarises CDM waste opportunities in Africa, before making a sustainable development comparison of five scenarios for waste management for the three elements of sustainability: economic, environmental and social. This paper provides conclusions on sustainable waste management in Africa and recommendations to the UNFCCC for an improved replacement to CDM beyond 2012.

2. Waste recycling and composting

Solid waste managed by municipalities is generally referred to as municipal solid waste (MSW). The specific types of wastes included in MSW vary significantly, but essentially comprise of materials, which can be recycled or composted.

2.1. Waste recycling

Every waste management practice generates GHG, both directly (i.e., emissions from the process itself) and indirectly (i.e., through energy consumption). However, the overall climate impact or benefit of the waste management system will depend on net GHGs, accounting for both emissions and indirect, downstream, GHG savings. The actual magnitude of these impacts varies significantly between nations due to different energy production and consumption trends. Estimates of GHG emissions from waste management practices tend to be based on life-cycle assessment (LCA) methods. However, there is a lack of data to carry out waste management LCA studies in many countries in Africa due to the key assumptions being based on such variables as local/regional waste composition, country-specific energy mix, and technology performance (Couth and Trois, 2010). These data are not necessarily transferable between countries. This makes it very difficult to make global comparisons regarding the GHG performance of different waste management technologies. This is illustrated in Table 1 (UNEP, 2010) where the amount of GHG emitted is expressed as carbon dioxide equivalent and is relative to a unit of activity (e.g., kgCO₂e per unit input) (BSI, 2007). Table 1 shows a significant range in kgCO₂e for materials (paper, aluminium, steel, glass and plastic) recycled in different countries demonstrating the difficulty in making global comparisons for emissions savings from recycling. GHG emission savings from applying the waste hierarchy are achieved through: reduced raw material extraction and manufacturing, recycled materials replacing virgin materials, compost replacing organic fertilizers, recovery of energy, avoided landfill emissions, and the carbon storage of the remaining fossil materials in landfill.

The climatic benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology (e.g., Anaerobic Digestion (AD), energy from waste (EfW), pyrolysis, gasification), even where energy is recovered during the process (EU 2008/98/EC (2008)).

The approach to calculating emissions from recycled inputs depends on the material (e.g., aluminium, ferrous metals, glass, plastic, paper) and whether the material recycling is part of a closed loop system or not. A closed loop system implies that when recycled, the material does not change and is used again for the same purpose. Greenhouse gas emissions from recycling materials are calculated in the European Union (EU) using British Standard Institution Publicly Available Specification (PAS) 2050 (BSI, 2008). The PAS 2050 method assesses the impact of GHG emissions arising from the life cycle of products over a 100-year period following the formation of the product. Where the life cycle of a product includes a material input with recycled content originating from the same product system, the emissions arising from that material shall reflect the product specific recycled content and/or recycling rate based on the calculation given below:

\[
\text{Emissions/unit} = (1 - R_1) \times EV + (R_1 \times ER) + (1 - R_2) \times ED
\]

Where \(R_1 = \) proportion of recycled material input, \(R_2 = \) proportion of material in the product that is recycled at end-of-life, \(ER = \) emissions arising from recycled material input, \(EV = \) emissions arising from virgin material input, \(ED = \) emissions arising from disposal of waste material, per unit of material.

Research into GHG emission factors (EF) for recycling are published for developed countries as provided in Table 2. The figures are expressed as CO₂e. GHG emissions are sometimes quoted in figures of mass of carbon equivalent, rather than CO₂e. References in Table 2 are included in the References at the end of this paper. To convert carbon equivalents into CO₂e, a multiplication factor of 44/12 must be applied. The producers of recycling emission factors for developed countries do not recommend that the factors are used by organisations or individuals in other countries, as the emission factors are specific to the country for which they are produced and many will vary to a very significant degree for other countries (Defra, 2009a). There are no such tables for countries across Africa, although figures have been prepared for other developing countries, e.g., India (Chintan, 2009). The figures in Table 2 do, however, give an indication of the emission savings that can be gained by recycling dry materials. It is recommended that similar tables should be developed for each country in Africa.

UNEP is developing methodologies for GHG emissions savings from dry waste recycling projects. There is currently a methodology for the recovery and recycling of high density poly-

### Table 1

<table>
<thead>
<tr>
<th>Material</th>
<th>KgCO₂e saved per tonne of material recycled</th>
<th>Northern Europe</th>
<th>Australia</th>
<th>USA</th>
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<td>838–937</td>
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<td>400–440</td>
<td>540</td>
<td>400–2000</td>
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<td>88</td>
<td>88–500</td>
<td>393</td>
<td></td>
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<td></td>
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</table>
The anaerobic degradation of biogenic waste in landfills generates CH4 which is a significant GHG with a global warming potential 21 times greater than CO2. However, the volume of methane produced can be significantly reduced by the composting of MSW prior to disposal. Anaerobic Digestion (AD) in purpose built engineered facilities is an alternative method to composting for the treatment of biogenic wastes. The main outputs from AD facilities are digestate (solid and/or liquid dependent on the type of technology used) and energy. The digestate may be used as a fertilizer as an alternative to compost. The advantage of AD over composting is energy recovery, providing that there is suitable infrastructure in place to harvest and export the energy produced. Also, AD requires less land than composting. However, it has the fundamental disadvantage that the process in technologically more complex to manage than composting, as well as requiring significant financial investment, and the effective management of AD technology is therefore questionable in the long term for many countries in Africa.

Greenhouse gas (GHG) emissions related to composting of organic waste and the use of compost include use of electricity and fuels in plant operation, and emissions of methane and nitrous oxide from the composting process itself. These process emissions are far outweighed by GHG emission savings from methane emissions from organic waste which would otherwise have been disposed to landfill; electricity and fuels used in the production of inorganic fertilizers or the excavation of peat; and use of the compost. Compost applied to land also reduces the need for pesticides, tillage (by improving soil structure and reducing erosion) and irrigation (by increasing water retention of the soil). The composting GHG emission savings depends on waste type and composition (kitchen organics, garden waste, MSW), technology type (open systems in Africa (open windrow, Dome Aeration Technology (DAT)), and the use of the compost. The overall global warming factor (GWF) for composting varies between significant savings (~900 kgCO2e per tonne of wet waste (ww)) to a net load (300 kgCO2e per tonne ww) (Boldrin et al. 2009). GHG savings from the avoidance of the manufacture of synthetic fertilisers are around 4–13 kgCO2e per kg of synthetic Nitrogen, whilst the substitution of peat has been estimated to save between 4 and 81 kgCO2e per tonne of composted waste (PROGNOS, 2008; Boldrin et al., 2009).

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 consists of two stages, active composting followed by maturation. For biogenic
waste composting to be successful (Haug, 1993) the oxygen concentration should be maintained above 15%; the temperature in the composting process should be 50–60 °C; the moisture content should be 50–55%; the carbon to nitrogen (C:N) ratio should be between 25:1 and 40:1 (Trois et al., 2007; SNIFFER, 2011); the pH should be neutral, i.e. between 6.5 and 8; there should be a small particle size to allow greater surface area for aeration; and the Respiration Index of the composted waste must be reduced to less than 5 gO2/kgDM (dry matter).

Crop residues and animal manure have traditionally been composted in long rows referred to as windrows. There are several options for the management of oxygen and moisture in windrows: the windrows can be turned with moisture added; air can be sucked on blown into the windrow; or pathways for air movement can be provided by Dome Aeration Technology (DAT) (Parr et al., 1999; Trois et al., 2005, 2007). In-vessel composters (IVCs) are an alternative to windrow composting and generally consist of metal tanks or concrete bunkers in which air flow and temperature can be more readily controlled, using the principles of a “bioreactor” (e.g. VCU, http://www.vcutechnology.com). IVCs are not considered applicable to many territories in sub-Saharan Africa due to reasons of cost, availability of technology and maintenance requirements.

In developed countries there is legislation for the quality of MSW compost that can be applied to land. Compost from MSW in Europe must comply with PAS 100: 2011 Specification for compost material (BSI, January 2011). This only permits compost from source segregated biowaste to be applied to land. The authors have researched similar standards for the application of biowaste to land in Africa and can find no similar legislation. For example, South Africa has no comparable legislation.

Likewise for composting projects, there is no market for composting projects without financial support. It is cheaper in the short term to dump waste than compost it. Markets for waste compost are not established in countries across Africa.

3. GHG emission saving opportunities in Africa

3.1. African potential

UNFCCC data show that of the fifty countries in sub-Saharan Africa, all but five (Botswana, Mauritius, Reunion, Seychelles and South Africa) had emissions below the 2.256 tCO2 per capita reported threshold to control global warming (UNFCCC, October 2005). The mean for sub-Saharan countries in 2004 was 1.0215 tCO2 per capita (Couth and Trois, 2009b). However, the source data for these figures is very questionable with significant variations between countries. The sub-Saharan countries recorded a massive increase in CO2 emissions between 1994 and 2004, between 222% and 307% for UNSD (United Nations Statistics Division) and CDIAC (Carbon Dioxide Information Analysis Center) figures respectively. These indicators show that 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 continue to increase as the urban population grows and people seek higher living standards. Consequently, there is a significant potential to limit GHG emission increases from urbanisation in Africa through improved waste management. This study has concluded to date that the average urban MSW waste production in Africa is around 230 kg/head/year of which the organic content is around 56% (Couth and Trois, 2010). With an urban population of over 0.4 billion, and a global warming potential (GWP) of CH4 of 21 compared with CO2, the GHG emissions from landfill gas for Africa equate to around 35 MtCO2e/year (Couth et al., 2011). The global warming impact of landfilling operations may be reduced by capturing and combusting the landfill gas. However, landfill gas management systems in Africa are typically only effective at collecting around 50% of the generated gas (World Bank, 2007), and would therefore only reduce this figure to 15 MtCO2e/year if all waste was disposed to landfill with effective landfill gas management systems (Couth et al., 2011). In comparison, composting schemes would prevent up to 100% of the landfill gas emissions by pre-treating the biogenic waste prior to final disposal. If dry recyclable materials are removed from the MSW before composting then there are further considerable emission reductions related to excavation of materials and manufacture of goods. Additionally, the compost will be of a quality to apply to land.

3.2. MSW compost GHG emission savings

GHG emission savings from MSW compost are calculated using methodological tool AM0025 and Annex 10 (IPCC, 1996, UNFCCC AM0025, 2008 and UNFCCC Annex 10, 2008). This calculates emissions (tCO2e) of CH4 from waste based on a first order decay landfill gas production curve. The quantity of emission reductions that can be claimed by a composting project is the emissions reductions that would have been gained from a landfill gas combustion project. This is only 50% of the GHG emissions over the period of the CDM project (7 years twice renewable, or 10 years).

Composting has the advantage that 98% of the emissions can theoretically be avoided during the period that the waste is disposed, whereas CDM landfill gas projects can only capture and combust around 50% of the emissions from the landfill gas production curve for the Registered CDM project period. Fig. 1 illustrates the bulk landfill gas production over a period of 40 years for the case study of MSW production of 230 kg/head/year at a 56% organic content for a population of 1,000,000. It shows the quantity of gas that can be practically captured and combusted over the 40 years, and that a composting project can theoretically avoid 98% of gas emissions over a period of 10 years. Fig. 1 shows that AM0025 does not provide CERs for 40 years of the landfill gas emissions avoided during the 10 year composting period. It also does not even provide for the bulk landfill gas emissions avoided during the CDM project period.

Consequently, whilst composting CDM projects lead to the immediate avoidance of nearly all methane emissions, CDM income is reduced and delayed. It is considered that this anomaly should be addressed by the UNFCCC, and that if the Kyoto Protocol is replaced, CERs should be paid for the CH4 emissions avoided from composting the waste as illustrated in Fig. 1. This would encourage waste composting projects in Africa which conform more closely to the waste hierarchy than landfill gas combustion and landfill gas to energy projects.

![Fig. 1. GasSim2 predictions on landfill gas emissions for cost benefit analysis.](image-url)
3.3. CDM opportunities

In February 2011, the CDM Pipeline web site (http://cdmpipeline.org) (CD4CDM, February 2011) was reporting:

i. 5872 CDM projects in the pipeline (Validated or awaiting Validation);

ii. 157 CDM projects in 24 African territories. This represents 2.7% of Validated projects or projects at Validation;

iii. six countries in Africa with 10 or more CDM projects (Egypt, Kenya, Morocco, Nigeria, South Africa and Uganda, with South Africa having the most (39, 23.7%));

iv. 101,144 ktCO₂e CERs from these projects by 2012;

v. 30 (19.1%) of the projects and 17% of the CERs were for the reduction of landfill gas emissions which includes landfill gas flaring, landfill gas power generation, combustion of MSW, gasification of MSW and landfill composting;

vi. four of the projects were landfill composting in Lagos, Nigeria (CDM 5034) (UNFCCC PDD, 2009)); Jinja, Uganda (CDM 2956) (UNFCCC PDD, 2009); Cairo, Egypt (CDM 3268) (UNFCCC PDD, 2007) and Khartoum, Sudan (CDM 6344) (UNFCCC PDD, 2010);

vii. 10 of the 30 projects in v. above include landfill gas to electricity; and

viii. 17 of the 30 projects in v. above include landfill gas flaring.

It is recognised that recycling and composting projects are poorly represented amongst all CDM projects. Composting projects only represent 9% of the UNFCCC CDM waste projects in 2010 (Rogger et al., 2011).

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 second PDD is for small scale waste composting projects through a Programme of Activities in Jinja Municipality in Uganda. The third CDM waste composting project in Lagos (UNFCCC PDD, 2009) involves the shredding of unloaded waste to <7 cm followed by windrow composting. The fourth CDM waste-composting project is in Khartoum, (Tawfig et al., 2009; UNFCCC PDD, 2010). In this fourth project the MSW is first sorted through a dirty materials recovery facility (MRF). The sorting stage is divided into waste receiving and pre-sorting, and sorting to remove bulky items (e.g. furniture, electrical equipment), plastics, glass, metals and cardboard. The selected biodegradable fraction is then aerobically composted in linear windrows (approximately 100 m long and 5 m wide). Water is added to the windrows using specialised spraying equipment to maintain optimum moisture content and facilitate the composting process. Purpose built machinery is used to turn the windrows regularly to maintain the aerobic degradation of the waste materials, enhance the composting process and improve homogeneity of the product. The oxygen and moisture content of the windrow composting material is monitored and controlled.

After a period of about one month, the windrow material is screened and stockpiled for a further month long maturation period. Following completion of the maturation and screening processes, the final product is sold as organic soil conditioner. The initial processing capacity is 960 tons MSW daily and is expected to double by 2013. After that, the capacity may be further extended, depending on the volumes of waste collected and market demand for compost. The project is estimated to lead to 1,197,250 tCO₂e emission reductions during the crediting period, at an average amount of 119,725 tCO₂e per year.

The four projects use the AM0025 CDM methodology and do not claim CDM credits for recycled materials. The UNFCCC does not have a methodology for the full reduction in carbon emissions from mechanical biological treatment projects.

4. Sustainable development comparison

Sustainable development was defined in the 1987 report of the Brundtland Commission, ‘Our Common Future’, as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’. The Report was welcomed by the UN General Assembly in its resolution 42/187 (United Nations, December 1987). The 2005 World Summit further defined sustainable development as ‘poverty eradication, changing unsustainable patterns of production and consumption and protecting and managing the natural resource base of economic and social development’ (United Nations, 2005). Consequently, to provide sustainable development three elements must be achieved, namely economic, environmental and social capital. The UNFCCC has methodologies for calculating carbon emission reductions but has no parallel methodologies for assessing sustainable development. A comparison of these three elements of sustainability is considered below for the following scenarios for waste management in Africa:

1. MSW composting in static DAT windrows;
2. shredded MSW composting in turned windrows;
3. dry recyclable material recovery and shredded MSW composting in turned windrows (MBT - mechanical biological treatment);
4. landfilling with gas flaring; and
5. landfilling with gas combusted to generate electricity.

The factors that need to be considered in a holistic approach to sustainable waste management are summarised in Table 3.

4.1. Economic sustainability comparison

The economic comparison between recycling and composting, and engineered landfill has been considered with and without CDM income. The economic comparison is based upon a cost-effectiveness model produced using Microsoft Excel, with spreadsheets for each of the above scenarios. Costs are based on capital expenditure (capex) and operational expenditure (opex) from the authors’ knowledge and experience of waste management and composting contracts in Africa. A quantitative cost comparison model has been prepared but the reported costs are subjective and project specific. The quantitative model calculates net present value and allows for inflation at the current South African rate, together with the cost of financing.

A cost comparison between composting and landfilling options is dependent on the amount of MSW that needs to be disposed. The
cost comparison model applies to urban waste and assumes a population of 1,000,000 generating 230 kg/head/year. An organic content of 56% has been used for the first order decay model calculation for the landfill gas generated. The assumption for the three composting scenarios is that the windrows are placed on a constructed hard standing and the surface water runoff is managed as dirty water. The dirty water is discharged and managed through a reed bed. 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 of the windrows although the moisture content can be controlled.

For the cost-effectiveness analysis, the assumptions which have been applied to all scenarios are given in Table 4 and are explained below:

(a) the CDM income is €16/\( t\text{CO}_2\text{e} \) per CER with 1.33 $/€ exchange and 7R$/€ exchange. It is assumed that it takes 12 months for CER Verification and Issuance by the UNFCCC, although some projects have taken considerably longer than this;
(b) a 10 year project life is taken, 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) a 7 year life for plant and equipment is assumed;
(d) a compost income of $2.3/t (WRAP, 2008) for sorted and shredded MSW composting with no income from other unsorted composting options;
(e) the land costs are €100,000/ha. This will be very variable in countries across Africa; and
(f) a discount rate of 3.5% (Treasury, 2011) to convert all capital (capex) and operational cost (opex) to net present values (NPV); an inflation rate of 3.7% (Trading Economics, 2011b); and venture debt of 20% (8.68% cost of the South African government borrowing for 10 years (Trading Economics, 2011c), plus 11–12% risk premium).

The cost-effectiveness model for the two landfilling 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-effectiveness model for the composting scenarios has continuous composting with 6 weeks composting followed by 11 weeks maturation. It is also assumed that the compost can be applied to land, with the compost from the sorted and shredded MSW in turned windrow option having a market value and being sold. The compost from MSW in static DAT windrows and shredded MSW in turned windrows options is not of a quality to be sold but may be used as an organic fertiliser. CDM income can theoretically be claimed for the emission savings from the avoided manufacture of compost achieved by the alternative use of waste compost. However, as such compost is not commercially generated in many countries in Africa, no allowance is made for this in the cost-effectiveness model. Organic compost does not substitute chemical fertilizers.

Income for the five scenarios is calculated as follows:

1. MSW composting in static DAT windrows;
   a. CERs from landfill gas at 98% avoidance; and
   b. avoided landfill disposal costs.
2. Shredded MSW composting in turned windrows;
   a. CERs from landfill gas at 98% avoidance; and
   b. avoided landfill disposal costs.
3. Sorted and shredded MSW composting in turned windrows (MBT (Mechanical, biological treatment));
   a. CERs from landfill gas at 98% avoidance;
   b. CERs from recycled materials;
   c. avoided landfill disposal costs;
   d. sale of recyclable materials; and
   e. sale of compost.
4. Landfilling with gas flaring;
   a. CERs from landfill gas at 50% landfill gas recovery and 97% combustion efficiency.
5. Landfilling with gas to electricity;
   a. CERs from landfill gas 50% landfill gas recovery and 97% combustion efficiency;
   b. CERs from the emission savings for the generation of electricity by fossil fuel (the 2010 published Eskom grid emission factor of 0.00103 tCO2e/kWh is used); and
   c. sale of electricity (standard purchase prices, no REFIT) (Couth et al., 2011).

The sorted and shredded MSW composting in turned windrows provides CDM income for the tCO2e emission saving from the reprocessing of dry recyclable materials against use of virgin materials together with the CDM income from avoided landfill gas generation. The CDM income is calculated from the rising landfill gas collected curve (50% of the gas generated) over 10 years in Fig. 1. Ten years is the selected CDM time period. The CDM income from carbon emissions saved in tCO2e from the reprocessed of recycled materials against manufacture from virgin materials is based upon Table 1 which is described in the environmental sustainability comparison made below. An income of $0.02/kWh is used for the sale of electricity. $0.02/kWh was the rate quoted by Eskom for the eThekwini Municipality CDM projects in 2009 (Couth et al., 2011). Eskom average prices have increased four times from since 2008 by 260% from $0.02/kWh (Aquasolar, 2011), however Eskom pay less than their average price for the supply of electricity to cover their transmitting and management costs.

The landfilling with gas to electricity option could provide additional income from higher prices paid for electricity generated by renewable fuels. However, few countries in Africa have renewable energy tariffs for electricity. The South Africa Government passed into law the Renewable Energy Feed-In Tariff (REFIT) mechanism in March 2009 to promote the deployment of renewable energy (NERSA, 2009), but this has yet to be applied to landfilling with gas to electricity projects in South Africa (Couth et al., 2011). The cost-effectiveness model includes a nominal avoided landfill disposal cost for the composting scenarios, $2/t. This equates to a cost saving to a municipality of $1.15 m/year in avoided landfill of the wastes for the modelled population of 1,000,000. Gate prices for disposal to landfill in the EU are calculated on the whole life costs for the management of the waste disposed in the landfills, and with Landfill Taxes can be of the order of $100/t. Gate prices for the dis-

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<td>Project life</td>
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</tr>
</tbody>
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posal of wastes to landfill are minimal in most countries in sub-Saharan Africa.

In calculating the costs for the options, the same land area is taken for the three composting options. DAT windrows may be larger as their size is not restricted by turning equipment and require a slightly smaller land area, however they have a lower overall density due to bulky material. The density of the compost depends on source material. For comparison, green waste windrow compost has a density around 550 kg/m³ and composting results in a reduction in the weight of around 35% (Defra, 2009b). The MBT option requires additional land for sorting and storage of dry recyclable materials, but less area for composting.

For the MBT option, it is recognised in Africa that recyclable materials are sorted and recovered when the waste is collected. However, in urban areas there remains a certain amount of dry recyclable materials in the waste (Couth and Trois, 2011). The cost-effectiveness model assumes 80% of the dry recyclables are captured from collected waste with an 80% recovery rate. Of the remaining materials, 80% are recovered at the MRF. Glass, paper and card recovered at the MRF will have little value, but ferrous metals, aluminium cans and plastic bottles will have a greater value. Net income from the sale of these materials is calculated based upon the tonnage of material captured multiplied by the net prices, where the net prices are the international prices for the materials less the collection, handling and transfer costs. The net income from CDM credits is based on the mean tCO₂e UNEP figures in Table 1, although it is considered that these underestimate the emissions saved as illustrated in Table 2. The costs for landfilling with gas flaring and landfills with gas to electricity calculates capex and opex for the operational costs for the landfill gas management systems for 10 years, but does not include any costs for the long term management of the landfills.

The ranking from the cost-effectiveness model with and without CDM income is identical and is as follows:

1. MBT – sorted and shredded MSW in turned windrows;
2. MSW in static DAT windrows;
3. shredded MSW in turned windrows;
4. landfilling with gas flaring; and
5. landfilling with gas to electricity.

Considering the cost-effectiveness model ranking:

1. Sorted and shredded MSW in turned windrows. This is the most favourable option from the cost-effectiveness model due to the income derived from dry recyclables and compost, although the value and security of the income from the sale of recyclables and compost is uncertain. The amortization period for this scenario is calculated as 3 years but is very dependent on income from recyclate. The five sources of income for this scenario listed above makes this scenario considerably more financially attractive than the other options. The most valuable income source is CERs from the recyclates. A tonne of aluminium cans gives a CDM income of $169,600 ($16 × 10,600 tCO₂e/t). It should however be noted that sorted and shredded MSW in a turned windrow 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. The 4 year amortization is dependent on the availability of dry recyclable materials and the CDM income from dry recyclable materials. The UNFCCC currently does not have a combined mechanical biological treatment methodology. If recyclable CDM income is excluded the amortization is 6 years which is longer that the other two composting options. The shredded MSW in turned windrows and MSW in static DAT windrows options could be favoured over the sorted and shredded MSW in turned windrows option as they have an existing UNFCCC CDM methodology, a lower capex, and therefore the need to resource less funding.

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 windrows option. It is questionable whether turning, air injection/exhaustion and moisture control equipment for windrow composting is technically viable in sub-Saharan Africa. However, 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.

3. Shredded MSW in turned windrows. The three CDM composting options are considerably more financially favourable than landfill disposal and gas collection options, as the waste is converted into a useable product and there are a number of sources of income. Also, 98% of the landfill gas is avoided (assuming 2% anaerobic conditions in the windrow), compared with 50% captured and combusted in the gas flaring and gas to electricity scenarios. It is assumed in the three composting options that: CDM income is based upon the rising profile of the bulk landfill gas production curve (Fig. 1); all three composting options generate the same CERs; composting is continuous and not a batch process; and there is no difference in the composting times in the static dome and turned windrows. The amortization period for this scenario is calculated as 5 years. The composting options are not attractive without CDM income. The composting options will not pay back in 10 years without CDM income.

4. Landfilling with gas flaring. Landfill gas flaring projects should be amortized within 7 years. Landfill gas flaring projects are not viable without CDM income (Couth et al., 2011). The GasSim2 analysis shows that a maximum of 8400 m³/hr of gas could 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 4200 m³/hr of landfill gas or around 2100 m³/hr of CH₄ gas combusted as extracted landfill gas typically contains around 50% CH₄. Landfill gas systems will need continued operation and management to capture carbon for at least 10 years after the landfill is closed. This cost is not included in the model. Landfill gas extraction with flaring is not viable without CDM income.

5. Landfilling with gas to electricity. Landfill gas to electricity CDM projects are only viable on the largest landfills in Africa (Couth et al., 2011). Landfill gas to electricity projects are not viable in Africa for waste from urban populations of less than 1,000,000 as the cost per 1 MW engine installed with a gas extraction system is over $1,000,000, and the engines require expert maintenance. The amortisation for this scenario is 8 years. Given the term of the investment and the uncertainty of technology for gas engines in Africa over 8 years, this option is not financially attractive.

The discounted cash flow for the five options is summarised in Table 5. The costs for the sorted and shredded MSW in turned windrows do not include CDM recyclate income. The final column of the table calculates the income per tonne of waste received averaged over the 10 year CDM period.

Similar simulation studies carried out in the early 2000s in India (Yedla, 2003). These compared a landfill system with gas recovery
against aerobic composting. The conclusion from this study was that the energy generating potential from MSW in the form of landfill gas performed better than aerobic composting for rates of waste generation greater than 1000–2000 tons per day (365,000–730,000 tons per year). The landfill system with gas recovery showed a better performance irrespective of the landfill collection system installation and operation costs. For both methodologies, unit cost of disposal was most sensitive to land rent followed by, in the case of landfill system with gas recovery, the organic content. This conclusion does not accord with the above modelling.

4.2. Environmental sustainability comparison

There are considerably greater environmental short and long term risks and liabilities from the disposal of waste to land (landfilling) against recycling dry waste materials and composting wet biogenic waste. Landfilled waste gives rise to hazards and adverse environmental impacts caused by it’s degradation, i.e. odour; potential hazardous air emissions; GHG emissions; leachate production; and potential groundwater pollution; visual intrusion; litter nuisance. Waste that is dumped to land remains an environment burden for future generations. Wet biogenic waste that is composted avoids the carbon emissions associated with landfill.

Dry waste that is recycled avoids the carbon emission associated with the excavation and processing of virgin materials against the reprocessing of recycled materials, and the depletion of natural resources. Significant research has been undertaken for developed countries to define the benefits of recycling plastics, metals, glass and paper (Astrup et al., 2009; Damgaard et al., 2009; Larsen et al., 2009; Merrill et al., 2009). However, the benefits have not been sufficiently quantified for the majority of countries in Africa. The informal waste sector makes a significant, but typically ignored, contribution to resource recovery and GHG savings in cities of developing nations.

The ranking of the projects in order or emission reductions is:

1. MBT – sorted and shredded MSW in turned windrows;
2. MSW in static DAT windrows;
3. shredded MSW in turned windrows;
4. landfilling with gas to electricity; and
5. landfilling with gas flaring.

This ranking reflects the cost-effectiveness model described above, with the exception of a reversal of landfilling with gas to electricity, and landfilling with gas flaring.

Further commentary on the ranking of the emissions comparison is as follows:

1. MBT – sorted and shredded MSW in turned windrows. Up to 98% of the emissions of CH₄ produced at solid waste disposal sites can be theoretically avoided (captured). This assumes that anaerobic conditions occur in 2% of the composting window (Trois et al., 2007). It also assumes that the compost is utilised as a fertilizer, avoiding the emissions which would otherwise occur from the production of manufactured fertilizer. In addition, there are considerable potential emission savings from the recovery of recyclable material. Emission savings from the use of recyclables is dependent on the material and the energy used in their production and processing. For example, the Zero Waste Plan for Scotland calculates the following emission savings from recycling: 9132 kgCO₂e/t aluminium; 1340 kgCO₂e/t ferrous metals; 1080 kgCO₂e/t paper; and 180–838 kgCO₂e/t glass (Scottish Government, 2010). Whilst it is recognised that recycling materials does provide emissions benefits, African waste will not provide as many CO₂e savings from recycling as waste from developed countries (Christensen et al., 2009). Without dry waste materials recycling, the carbon emissions benefit of avoiding landfill disposal is calculated as around 35 MtCO₂e per annum in Africa (Couth et al., 2011).

2. MSW in static DAT windrows. This will give the same savings of emissions of CH₄ produced at solid waste disposal sites as the sorted and shredded MSW in turned windrows MBT scenario, but the quality of the compost will not be as good from MSW as dry recyclable material will remain within the waste. Whether the compost can be used as a fertilizer (soil substitute) will depend upon any laws within the individual country regarding the application of compost to land.

3. Shredded MSW in turned windrows. The emission savings from this scenario is very similar to composting MSW in static DAT windrows, but is slightly worse as energy needs to be used in turning the windrows.

4. Landfilling with gas to electricity. Landfills typically capture approximately 50% of the gas generated (World Bank, 2007). Consequently, whereas composting can theoretically avoid up to 98% of the landfill gas emissions, landfill gas extraction and combustion can save around 50% of the emissions (Fig. 1). Landfilling with gas to electricity allows emissions from the combustion of fossil fuels to generate electricity to be saved, so it is ranked above landfilling with gas flaring, a reverse of the economic ranking. The two landfilling options are environmentally less sustainable than the composting option as waste which is disposed to land biodegrades and produces landfill gas and leachate which are hazards to the environment and humanity for generations.

5. Landfilling with gas flaring. This is the least environmentally favourable of options, but it is still more environmentally favourable than allowing landfill gas to vent to atmosphere. It is the main solution that has been adopted for UNFCCC CDM waste projects.

The climate benefits of waste practices result from avoided landfill emissions, reduced raw material extraction and manufacturing, recovered materials and energy replacing virgin materials and fossil-fuel energy sources, carbon bound in soil through compost application, and carbon storage due to recalcitrant materials in landfills. In particular, there is general global consensus that the climate benefits of waste avoidance and recycling far outweigh the benefits from any waste treatment technology, even where energy is recovered during the process (WRAP, 2006; UNEP, 2010).
The Scottish Government is now setting carbon targets for waste management with focus on targeting dry recyclable materials (Scottish Government, 2010). It is recommended that the carbon baseline from waste management is calculated for countries in Africa; targets are proposed to manage and reduce these emissions; and the UNFCCC introduces a new mechanism for Annex 1 countries to fund developing countries to meet these carbon targets.

4.3. Social sustainability comparison

This second objective of CDM of sustainable development has been assessed by many projects (Olsen, 2007; Rogger et al., 2011; Sutter and Parreño, 2007). It is concluded that many CDM projects do not contribute significantly to sustainable development, and that the CDM does not offer adequate incentives to host countries to achieve the second goal of sustainable development. A shift in mind set in favour of the second objective will only happen when value is attributed to sustainability. Climate change organisations have sought to develop a measure for sustainable CDM projects (e.g. the Gold Standard) but this has yet to be adopted by the UNFCCC (Gold Standard, 2011). The Gold Standard rewards CDM Projects in terms of their contribution to sustainable development leading to a higher value for CERs generated. There are Gold Standard CERs and VERs (Verified Emission Reductions). However these currently exclude landfill projects, including composting.

Waste management projects have the social benefit of providing 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. They also contribute to knowledge and technology transfer.

The social ranking of the five options is:

1. MBT – sorted and shredded MSW in turned windrows. This option has the advantage of providing direct local employment through waste picking, with the potential for over 100 jobs per scheme, and the advantage of providing indirect employment through waste reprocessing (Tawfig et al, 2009);
2. MSW in static DAT windrows and shredded MSW in turned windrows. These options will provide similar employment opportunities from the management of waste composting and application to land. More people should be directly employed through waste composting than landfilling. People currently living on landfills who pick waste as it is dumped can be employed in the managed picking of wastes prior to composting;
3. landfilling with gas to electricity. This provides some local employment through the engagement and training of engineers to manage the engines. However well being is reduced though exposure of the local community to landfill and landfill related activities; and
4. landfilling with gas to electricity. Similar to landfilling with gas to electricity but slightly less employment and technician training.

4.4. Sustainability comparison conclusions

The overall sustainability ranking of economic, environmental and social impacts of the five options is:

1. MBT – sorted and shredded MSW in turned windrows;
2. MSW in static DAT windrows;
3. shredded MSW in turned windrows;
4. landfilling with gas to electricity; and
5. landfilling with gas flaring.

However, landfilling with gas to electricity is only viable for large projects and requires greater funding and technological management.

The sustainability ranking accords with the waste hierarchy as detailed in the EU Waste Framework Directive (EU 2008/98/EC (2008)). It demonstrates that where waste is generated, it will be most sustainable to prepare the waste for re-use and recycle, rather than landfill with landfill gas combustion and energy recovery. It is difficult to have a Waste Management Strategy for Africa, but one should focus on the waste hierarchy. All Waste Management Strategies for countries in Africa should be holistic, providing a sustainable integrated approach with consideration to economics, the environment and social issues.

5. Conclusions and recommendations

In a global context, the management of wastes was estimated to produce 3–5% of the total anthropogenic GHG emissions in 2005 (UNEP, 2010). The percentage in Africa is higher due to largely uncontrolled waste disposal practices (Couth and Trois, 2011). Although a reasonable proportion of emissions are released through waste disposal, the prevention, recycling and composting of waste avoids significant emissions in other sectors of the economy, i.e. energy, forestry, agriculture, mining, transport, and manufacturing.

Africa has the highest proportion of Least Developed Countries (LDCs) of the five continents (Africa, Americas, Asia, Australasia and Europe). Sub-Sahara Africa has 33 LDCs, whilst there are only 14 LDC in Asia and one LDC in the American Pacific. The majority of the people in sub-Saharan Africa live in a rural setting with an average income per capita as low as $596 (Couth and Trois, 2009a). The urban population is however increasing at a significant rate but there is not the income to treat and dispose of wastes (Couth and Trois, 2009a). Urban waste in sub-Saharan Africa has a high biodegradable content (around 56%), it is dumped and it therefore produces a high percentage of carbon emissions per capita (Couth and Trois, 2010). The high and increasing rate of carbon emissions per capita and the non availability of reliable data for waste management and the population in sub-Saharan Africa is a challenge.

The sustainability analysis shows that waste recycling and 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. Under this option, compost and recyclable materials may be sold; CDM income gained from recycled materials and displaced landfill gas; and landfill disposal costs may be avoided.

Waste recycling and composting projects fulfill the CDM objectives better than landfill disposal projects. Composting projects provide twice the reduction in GHG emissions when compared to landfill gas combustion projects. The GHG emission reductions can be effectively provided over the period of waste production rather than over a generation. They are more sustainable in developing countries and do not leave an environmental hazard for future generations.

Landfill CH4 emissions are increasing in developing countries because of larger quantities of MSW from increasing urban populations, increasing economic development and, to some extent, the replacement of open burning and dumping by engineered landfills. Without additional measures, a 50% increase in landfill CH4 emissions from 2005 to 2020 is projected, mainly from the Non-Annex I countries (IPCC, 2007; Couth et al., 2011).
The UNFCCC does not currently have an approved CDM methodology to value the emission savings from recycled materials; it does not have a methodology for composting that correctly calculates the emissions avoided; and it does not have a methodology that rewards the second CDM objective of sustainable development. Landfill gas CDM projects do not contribute as significantly to sustainable development as waste recycling and composting projects. The UNFCCC should distinguish between the sustainability of landfill category CDM projects and value CERs accordingly, similar to the Gold Standard (Gold Standard, 2011). More sustainable CERs should then achieve a higher value on the world markets. CDM methodologies need to be developed for these parameters.

In summary, it is considered that the UNFCCC should:

(a) renew and develop CDM through a replacement to the Kyoto Protocol focusing on sustainable projects in developing countries. MBT and composting projects in Africa are unlikely to proceed without funding from Annex 1 developed countries through a replacement to the CDM;

(b) develop a mechanism to grade CDM projects and the resulting CERs depending upon their sustainability (as in the Gold Standard). The definition of “sustainability” for these projects should be defined. CERs from more sustainable projects should have a higher value and thereby generate more income. CDM methodologies should take account of the wider social costs and benefits of proposals, and the need to ensure the proper use of public resources. These CDM methodologies should reward the informal sector;

(c) establish the current direct and indirect baselines for carbon emissions from waste management for individual countries in Africa and set carbon emission targets. Most countries in Africa have universities and the waste management carbon emission baselines could be determined by the universities against UNFCCC criteria. These carbon emission targets should then be met through new projects funded by the replacement to the Kyoto Protocol;

(d) develop a CDM methodology for small scale mechanical biological treatment (MBT) projects. This should include all dry recyclable waste materials and wet compostable biogenic wastes. CERs should be for the total gas emissions avoided by composting biogenic wastes, not the landfill gas captured and combusted over the CDM landfill period;

(e) calculate tables for emission savings from closed loop recycling and use of dry materials for each country in Africa;

(f) specify a standard for the application of waste compost to land in countries in Africa; and

(g) amend the existing AM0025 composting methodology to provide CERs for the total emissions avoided during the life of the composting project.

Waste generation is related to population, affluence and urbanisation. Recycling and composting can provide an affordable, sustainable alternative to engineered landfills, especially where more labour-intensive, lower-technology strategies are applied to the recyclable and biodegradable waste streams. The truth is that there are millions of informal poor, including recyclers, whose work contributes to emissions reductions, but who remain unaccounted for, and unrewarded for protecting our global community. Mechanisms should be adopted to ensure that such efforts are accounted for, and that those involved are rewarded accordingly.

Whereas developed countries such as the United States, Canada, and Australia emit over 20 tCO2e per capita per year (Chintan, 2009), sub-Saharan African countries emit an average of just over 1 tCO2e per capita per year (Couth and Trois, 2009b). UNFCCC targets to reduce carbon emissions by 85% by 2050 to control the global temperature rise to 2 °C (Metz, 2008), will only be met if initiatives are progressed with regard to waste management practices in developing countries.

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