Waste Management 31 (2011) 131–137

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Waste management activities and carbon emissions in Africa

R. Couth, C. Trois *

University of KwaZulu-Natal, CRECHE, School of Civil Engineering, Survey and Construction, Durban 4041, South Africa

ARTICLE INFO

Article history:
Received 25 January 2010
Accepted 6 August 2010
Available online 15 September 2010

ABSTRACT

This paper summarizes research into waste management activities and carbon emissions from territories in sub-Saharan Africa with the main objective of quantifying emission reductions (ERs) that can be gained through viable improvements to waste management in Africa. It demonstrates that data on waste and carbon emissions is poor and generally inadequate for prediction models. The paper shows that the amount of waste produced and its composition are linked to national Gross Domestic Product (GDP). Waste production per person is around half that in developed countries with a mean around 230 kg/hd/yr. Sub-Saharan territories produce waste with a biogenic carbon content of around 56% (+/−25%), which is approximately 40% greater than developed countries. This waste is disposed in uncontrolled dumps that produce large amounts of methane gas. Greenhouse gas (GHG) emissions from waste will rise with increasing urbanization and can only be controlled through funding mechanisms from developed countries.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) unequivocally demonstrates that most of the observed Earth's temperature increase since the middle of the 20th century was caused by increasing concentrations of Greenhouse gasses (GHGs) resulting from human activity such as fossil fuel burning and deforestation (IPCC, 2007). In spite of nearly 20 years of international attention since the Rio Earth Summit, emissions of GHGs (principally CO_2 from the combustion of fossil fuels for energy) continue to grow rapidly. Substantially adverse effects on food production, water supply, and ecosystems are projected for highly vulnerable areas like sub-Saharan Africa.

The annual GHG emissions ceiling for the world, in order to control global warming, is considered to be 2.256 tCO_2 per capita (14.5 $GtCO_2$). This is less than half of the actual 2004 emissions threshold of 4.56 tCO_2 per capita (29 $GtCO_2$) (UNSD, 2008). In 2004, citizens in the USA produced 20.6 tCO_2 per capita, over 200 times the figure of 0.1 tCO_2 per capita for some countries in sub-Saharan Africa. In 2004, carbon emissions in the Republic of Chad were 0.0127 tCO_2 per capita compared with a mean of 1.0215 tCO_2 per capita in sub-Saharan Africa (Couth and Trois, 2009b). The amount of carbon emissions (tCO_2) per capita produced in Africa against the rest of the world is summarized in Table 1.

This shows that whilst sub-Saharan Africa has around 12% of the world's population, it makes less than 3% of the world's carbon emissions.

All Annex 1 Parties (developed countries) to the Kyoto Protocol are required to annually monitor, control and report their carbon emissions. There is no such requirement for Non-Annex 1 Parties (developing countries). Reporting of carbon emissions by Non-Annex 1 Parties is voluntary and sporadic, and GHG inventories for biological sectors such as waste are characterized by methodology limitations, lack of data, low reliability of existing data, and high uncertainty levels. Carbon emissions for African territories are provided in the Sixth compilation and synthesis report (UNFCCC, October 2005). The report covers inventory information and related methodological issues identified by 122 of the 148 Non-Annex 1 Parties (82%) who estimated, at least for one year, emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

The UN Commission on Sustainable Development (CSD) indicators relevant to waste management and carbon emissions include: carbon dioxide (CO_2) emissions, emissions of other GHGs, generation of waste, and waste treatment and disposal.

These indicators show that 6.8% of the GHG emissions for Africa are from waste and greater than the average of 4.2% for other Non-Annex I parties (Couth and Trois, 2009b). The data show that the mean 4.4383 tCO_2 per capita estimated in 2004 for North African countries is almost double the 2.256 tCO_2 per capita figure required to control global warming, and very similar to the world average of 4.56 tCO_2 per capita. It is also notable that there was an increase in GHG emissions from North African countries from 44% to 69% between 1994 and 2004.

Of the 50 countries in sub-Saharan Africa, only four (Botswana, Mauritius, Reunion and Seychelles) recorded emissions above the 2.256 tCO_2 per capita threshold. A further four countries recorded

* Corresponding author. Tel.: +27 (0) 31 2603065/55; fax: +27 (0) 31 2601411.
E-mail address: troisc@ukzn.ac.za (C. Trois).

0956-053X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.wasman.2010.08.009

Table 1
Summary of the World's population and carbon emissions (Couth and Trois, 2009b).

Location	Population	Mean CO_{2e} t/capita	Total (Gt CO_{2e})	Percentage CO_{2e} (%)	Percentage population (%)
World	6670,000,000	4.56	30.42	100	100
Africa	1000,000,000	1.70	1.70	5.6	15
North Africa	200,000,000	4.44	0.89	2.9	3
Sub-Saharan Africa	800,000,000	1.02	0.82	2.7	12

emissions between 1 and 2 tCO_2 per capita, with the remaining 42 sub-Saharan countries recording emissions below 1 tCO_2 per capita. South Africa is an exception; recording emissions at 9.1927 tCO_2 per capita in 2004, approximately double the global average. The mean for sub-Saharan countries in 2004 was 1.0215 tCO_2 per capita, and excluding South Africa the mean lowers to 0.8547 tCO_2 per capita. However, sub-Saharan countries recorded a massive increase in CO_2 emissions between 1994 and 2004, ranging between 222% and 307% for UNSD and CDIAC figures, respectively (Tables 2 and 3). These figures will continue to grow as the population becomes more urbanized.

Table 2 provides for 55 territories in Africa (excluding Canary Islands, Ceuta (Islands), Lesotho (Kingdom of Lesotho), Madeira (Island), Mayotte (Island) and Melilla (Autonomous City of Melilla)) details of the following:

- UNSD tCO_{2e} per capita for 1994 and 2004, and the percentage change;
- CDIAC 1000 tCO_{2e} for 1994 and 2004, and the percentage change; and
- LDC (least developed countries), LLDC (landlocked developing countries), SIDS (small island developing States) and World Bank income grouping for both Sub-Saharan and North Africa. The majority of territories are in a low World Bank income group, but some are among lower and upper middle-income groups.

Table 3 provides, for 42 territories in Africa:

- National Inventory Reports (NIR) from the UNFCCC sixth compilation and synthesis of initial national communications from Parties not included in Annex 1 to the Convention (UNFCCC, October 2005). NIR for the majority of the territories are for 1994/5;
- CO_{2e} emissions with and without LUCF (Land-Use Change and Forestry);
- CO_{2e} from waste activities and the percentage of the total CO_{2e} that this represents;
- CO_2, CH_4 and N_2O emissions; and
- percentage of CH_4 to CO_2.

From Tables 1–3, it is evident that reported carbon emissions from waste management activities for African territories are very fragmented. The maximum tonnage of carbon emissions from waste is recorded in Nigeria, which monitors and reports on CH_4 emissions from landfill sites, although the maximum percentage of GHG emissions from waste management is reported as 72.9% in Gambia. Methane emissions from uncontrolled dumpsites form a significant proportion of GHG emissions in African territories. Uncertainties in the way carbon emissions from waste are monitored, generally result in the inability of African countries to attract external funding to improve waste management systems and achieve sustained emission reductions.

This paper presents the findings of research into waste production and management in Sub-Saharan countries, which form part of a larger study into the effective reduction of carbon emissions in Africa through improved waste management strategies. The main objectives of this study are to provide a clear understanding of emission reductions (ERs) that can be gained through viable improvements to waste management in Africa and to develop guidelines on the implementation of such projects. The study intends to fill the knowledge gap on the impact of carbon emissions attributable to solid waste management across Africa.

2. Methodology

Of the 61 territories in Africa, countries, which were representative of small and large territories in north and Sub-Saharan Africa with a wide range of GDPs, were selected for this study. Initially 19 territories were identified, 1 in North Africa (Egypt) and 18 in sub-Saharan Africa (Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe). An electronic questionnaire was prepared to obtain data to inform a waste management life cycle assessment model designed to determine current carbon emissions from waste management practices in Africa, and assess viable deliverable options to reduce their global impact.

The questionnaire was e-mailed to named contacts (primarily waste regulators/managers) in the 19 territories in October 2008. The majority of the contacts were regulatory officials. At the end of this exercise in 2009, we received suitable replies from only six countries, resulting in a 32% response rate. However, the quality of the data was very poor, and generally related to the municipality in which the respondent worked and not necessarily representative of the entire country.

More information was then sought from NEPAD (the New Partnership for Africa's Development) (http://www.nepad.org/). NEPAD is the strategic framework for Africa's renewal and is designed to address the current challenges facing the African continent. Subsequently, details were received from seven NEPAD contacts covering 12 territories – Algeria, Saharawi Arab Democratic Republic, Cameroon, Central African Republic, Chad, Ethiopia, Eritrea, Djibouti, Libya, Mali, Mauritania and Niger.

Prior to sending the questionnaire to the NEPAD contacts, it was recognised that some of the data requested are not available for sub-Saharan territories. Also, it was considered that the respondents might view the questionnaire as potentially time consuming to complete. Consequently, the questionnaire was simplified into 20 response boxes with reference to web sites where appropriate. By February 2009, qquestionnaires requesting simple waste management data had been sent out to 26 contacts, covering 31 territories in Africa. Most of them returned unanswered. The reasons behind the limited response to the original questionnaire on waste and management activities in African territories were considered. It was concluded that many territories in Africa do not currently possess or record reliable waste management data, which is generally site/city specific. It was also concluded that, as many of the named contacts are not personally known to the authors, there was not sufficient motivation to provide the requested data. Consequently it was concluded that waste data should be sought for spe-

Table 2
UNSD and CDIAC CO_2 data against UN and World Bank country classification (Worldwatch Institute, 2009).

Country	Tonnes CO_2 per capita. (Last updated 1st August 2007) UNSD			1000 tonnes CO_2. (Last update 14th July 2008) CDIAC			LDC[a]	LLDC[b]	SIDS[c]	World Bank
	1994	2004	% Increase, 10 years	1994	2004	% Increase, 10 years				Income group (2007)
Algeria	3.1138	5.994	92	86333.6	194001.2	125				Lower middle
Angola	0.3509	0.5051	44	4197.9	7897.2	88	x			Low
Benin	0.2108	0.2902	38	1264.9	2386.7	89	x			Low
Botswana	2.2768	2.3693	4	3479.3	4300.5	24		x		Upper middle
Burkina Faso	0.0952	0.0812	−15	949.6	1096.2	15	x	x		Low
Burundi	0.0345	0.0291	−16	212.6	220.0	3	x	x		Low
Cameroon	0.2664	0.2205	−17	3647.9	3838.6	5				Low
Cape verde	0.2809	0.5553	98	110.0	275.0	150	x		x	Lower middle
Central African Republic	0.0698	0.0614	−12	234.6	253.0	8	x	x		Low
Chad	0.0138	0.0127	−8	95.3	124.7	31	x	x		Low
Comoros	0.1118	0.1132	1	66.0	88.0	33	x			Low
Congo	0.7764	1.0034	29	2108.1	3541.6	68				Low
Cote d'Ivoire	0.3432	0.2825	−18	4993.5	5162.1	3				Low
Democratic Republic of the Congo	0.059	0.037	−37	2595.7	2104.4	−19	x			Low
Djibouti	0.6002	0.4639	−23	366.6	366.6	0	x			Lower middle
Egypt	1.4241	2.2116	55	84790.1	158236.6	87				Lower middle
Equatorial Guinea	0.3343	11.4748	3332	124.7	5426.1	4253	x			Low
Eritrea	0.0575	0.1735	202	183.3	755.3	312	x			Low
Ethiopia	0.0499	0.1037	108	2918.4	7981.5	173	x	x		Low
Gabon	3.3319	1.0796	−68	3428.0	1371.2	−60				Upper middle
Gambia	0.187	0.1821	−3	209.0	286.0	37	x			Low
Ghana	0.2859	0.326	14	4982.5	7189.6	44				Low
Guinea	0.1677	0.1515	−10	1187.9	1338.2	13	x			Low
Guinea-Bissau	0.1968	0.1752	−11	227.3	271.3	19	x		x	Low
Kenya	0.2453	0.3054	25	6526.0	10588.2	62				Low
Liberia	0.1505	0.1401	−7	311.6	469.3	51	x			Low
Libyan Arab Jamahiriya	8.2847	10.331	25	39243.9	59914.3	53				Upper middle
Madagascar	0.0937	0.1506	61	1268.5	2731.4	115	x			Low
Malawi	0.0704	0.081	15	700.3	1044.9	49	x	x		Low
Mali	0.0543	0.0501	−8	462.0	564.6	22	x	x		Low
Mauritania	1.4159	0.8866	−37	3065.0	2555.4	−17	x			Low
Mauritius	1.4622	2.598	78	1624.2	3197.0	97			x	Upper middle
Morocco	1.1167	1.3654	22	29645.5	41168.7	39				Lower middle
Mozambique	0.069	0.1079	56	1063.2	2166.8	104	x			Low
Namibia	0.0182	1.2394	6710	29.3	2471.1	8325				Lower middle
Niger	0.1215	0.0947	−22	1088.9	1213.5	11	x	x		Low
Nigeria	0.4401	0.8263	88	46649.7	114025.0	144				Low
Reunion	2.6622	2.9432	11	1734.2	2276.8	31				
Rwanda	0.0843	0.0632	−25	483.9	571.9	18	x	x		Low
Saint Helena	1.4175	1.7398	23	7.3	11.0	50				
Sao Tome and Principe	0.5839	0.6106	5	73.3	91.7	25	x		x	Low
Senegal	0.4367	0.4353	0	3849.6	4993.5	30	x			Low
Seychelles	2.4973	6.4395	158	187.0	546.3	192			x	Upper middle
Sierra Leone	0.1216	0.1843	52	502.3	993.6	98	x			Low
Somalia	0.0018			11.0			x			Low
South Africa	8.8438	9.1927	4	358525.5	437031.6	22				Lower middle
Sudan	0.1424	0.287	102	4091.6	10371.9	153	x			Low
Swaziland	0.5145	0.8589	67	483.9	956.9	98		x		Lower middle
Togo	0.1807	0.3805	111	791.9	2309.8	192	x			Low
Tunisia	1.8032	2.2895	27	15937.3	22884.9	44				Lower middle
Uganda	0.0362	0.0651	80	744.3	1825.8	145	x	x		Low
United Republic of Tanzania	0.0828	0.116	40	2405.1	4351.9	81	x			Low
Western Sahara	0.8036	0.5726	−29	201.6	238.3	18				Lower middle
Zambia	0.2681	0.203	−24	2419.7	2287.8	−5	x	x		Low
Zimbabwe	1.6241	0.8106	−50	18782.4	10558.9	−44		x		Low

[a] Least developed country.
[b] Landlocked developing country.
[c] Small island developing state.

cific cities in Africa, and the questionnaires directed to known individuals.

Contact was made with the University of Natural Resources and Applied Life Sciences in Vienna, as they are involved with ROSA (**R**esource-**O**riented **S**anitation concepts for peri-urban areas in **A**frica) projects for four cities in east Africa: Arba Minch, Ethiopia (74,000 inhabitants); Nakuru, Kenya (400,000 inhabitants); Arusha, Tanzania (359,000 inhabitants); and Kitgum, Uganda (40,000 inhabitants). The primary objectives of the ROSA project are to improve excreta, grey-water and domestic solid waste management in Africa. Contact details were obtained and questionnaires were sent to universities in Arba Minch, Nakuru and Arusha. Data were not sought for Kitgum as the original questionnaire had been completed for Kampala (Uganda). In seeking information from the University of Arba Minch in Ethiopia, data were also requested for Addis Ababa (3384,000 inhabitants). In addition, contact details

Table 3
UNFCCC sixth compilation Non-Annex 1 Parties (UNFCCC, 2005).

Party	Year	Total (without LUCF) Gg	Total (with LUCF) Gg	Waste Gg	Percentage	Emissions CO_2 Gg	Emissions CH4 Gg	Emissions N_2O Gg	Percentage CH_4/CO_2 (%)
		One millions tonnes CO_{2e} = 10°				One millions tonnes CO_{2e} = 10°			
Algeria	1994	91607.24	100194.24	4720.00	5.2	63703.74	894.00	29.45	1.4
Benin	1995	39347.62	−8175.79	295.81	0.8	802.34	1810.24	1.71	225.6
Botswana	1994	9291.74	−29441.86	171.80	1.8	3014.50	201.84	6.58	6.7
Burkina Faso	1994	5968.26	6060.07	351.59	5.9	902.00	223.83	1.18	24.8
Burundi	1998	995.43	−1003.00	103.96	5.2	143.18	44.91	2.93	31.4
Cameroon	1994	165725.02	187911.39	1730.19	1.0	2769.52	843.30	468.54	30.4
Cape Verde	1995	292.89	329.41	33.71	11.5	217.73	3.29	0.02	1.5
Central African Republic	1994	38343.90	−102513.64	2565.26	6.7	212.00	563.70	84.82	265.9
Chad	1993	8021.06	−38177.06	412.43	5.1	309.65	330.36	2.50	106.7
Comoros	1994	518.94	−376.18	9.96	1.9	70.52	2.64	1.27	3.7
Congo	1994	1374.88	−68485.80	147.38	10.7	673.70	27.78	0.38	4.1
Cote d'Ivoire	1994	24725.27	4877.86	8837.58	35.7	4345.77	889.56	5.48	20.5
Democratic Republic of the Congo	1994	44532.51	−132307.70	6056.64	13.6	1338.95	1935.08	8.25	144.5
Djibouti	1994	511.44	−88.06	29.57	5.8	274.15	11.23	0.00	4.1
Egypt	1990	117266.11	107366.11	5688.06	4.9	84459.00	1055.91	34.30	1.3
Eritrea	1994	4135.21	5811.51	53.97	1.3	719.84	73.77	6.02	10.2
Ethiopia	1994	47414.90	33008.20	1428.90	3.0	2597.00	1779.90	24.00	68.5
Gabon	1994	6524.33	−494351.36	94.59	1.4	4407.74	55.59	3.06	1.3
Gambia	1993	4242.48	−45740.60	3094.66	72.9	181.06	190.26	0.21	105.1
Ghana	1994	12578.39	−6894.28	473.09	3.8	3329.80	396.95	2.94	11.9
Guinea	1994	5057.70	−12538.95	341.38	6.7	1580.49	154.74	0.73	9.8
Kenya	1994	21466.23	−6533.99	318.89	1.5	5511.96	739.86	1.35	13.4
Lesotho	1994	1820.30	3080.87	54.57	3.0	635.99	46.21	0.69	7.3
Madagascar	1994	21933.66	−217037.34	210.00	1.0	1146.17	369.29	42.04	32.2
Malawi	1994	7070.34	24585.88	90.09	1.3	719.26	187.88	7.76	26.1
Mali	1995	8666.20	−1081.94	115.53	1.3	954.61	340.82	1.79	35.7
Mauritania	1995	4329.86	3689.88	229.35	5.3	1046.67	155.38	0.07	14.8
Mauritius	1995	2058.85	1837.49	71.53	3.5	1738.43	4.60	0.72	0.3
Morocco	1994	44373.00	39862.00	2284.00	5.1	28364.00	349.00	28.00	1.2
Namibia	1994	5602.16	−34.18	71.61	1.3	1826.63	168.86	0.74	9.2
Niger	1990	4856.31	10962.55	28.07	0.6	598.47	163.64	2.65	27.3
Nigeria	1994	242626.40	347636.38	44004.37	18.1	114815.82	5912.16	11.79	5.1
Senegal	1994	9317.90	3320.94	2226.21	23.9	4005.50	251.82	0.08	6.3
Seychelles	1995	256.41	−576.36	49.35	19.2	178.74	2.56	0.08	1.4
South Africa	1994	379837.38	361221.42	16429.07	4.3	315957.24	2057.44	66.69	0.7
Sudan	1995	54237.00	72014.00	1003.00	1.8	4501.00	1896.00	32.00	42.1
Swaziland	1994	2635.98	−617.08	346.54	13.1	873.87	64.17	1.34	7.3
Togo	1995	4996.32	25292.98	6.75	0.1	1277.94	44.50	8.98	3.5
Tunisia	1994	25140.99	23368.29	1032.13	4.1	17096.40	180.15	13.75	1.1
Uganda	1994	42604.27	50856.97	95.05	0.2	730.25	1269.15	49.10	173.8
Tanzania	1994	39235.89	952798.83	2247.48	5.7	3224.73	1030.23	46.38	31.9
Zambia	1994	32769.33	36327.29	1415.19	4.3	2595.36	509.75	62.80	19.6
Zimbabwe	1994	27594.14	−34645.30	528.15	1.9	17088.48	358.26	9.62	2.1
Total Africa		1612904.22	1201794.07	109497.46	6.8	700940.20	27590.61	1072.79	3.9

were obtained and a questionnaire was sent to Windhoek in Namibia (300,000 inhabitants).

The questionnaire used in both information campaigns sought 22 items of data under six categories (Table 4):

- Population: to establish the size of the city;
- Information sources: to provide websites for further legislative requirements for waste management and environmental data for the city;
- Waste data: tonnages of annual waste production, recycling, composting and disposal;
- Waste composition: percentages for paper and card, glass, metals, plastics, organic/biodegradable and inert waste;
- Landfill details: controlling legislation, number and size, capped and restored, and landfill gas flaring systems; and
- CDM projects: registered and proposed waste composting and landfill gas projects.

A preliminary background study (Couth and Trois, 2010) detailed differences in waste management between serviced urban communities and semi or non-serviced peri-urban communities, which are defined as "large sprawling settlements lacking most urban amenities with a population density around 250–1000 persons per km^2" (Muniafa and Otiato, 2008). Consequently it was decided to seek waste management data for peri-urban communities in Cape Town and Durban, South Africa.

The questionnaire to Cape Town and Durban sought 16 sets of data under five of the six categories listed above for the east African cities. The category for Information sources was removed as information on waste management activities in Cape Town and Durban was already known by the authors. The category on landfill details was amended to request details of landfills constructed and operated in accordance with 'Minimum Requirements'. All landfills in South Africa should be designed, constructed, operated, restored and subsequently maintained in accordance with the Minimum Requirements for Disposal of Waste by Landfill (DWAF, 1998 and 2005).

With the urban population increasing and shortages of finance for sanitation, Africa contains some of the dirtiest cities in the world. Of the top 25 dirtiest cities in the world, 15 (60%) are in Africa (Globalisation and the environment, 2008). These include Addis Ababa (Ethiopia) (3.4 million inhabitants) and Dar es Salaam (Tanzania) (2.5 million inhabitants). All of these 15 dirtiest cities

Table 4
Data acquisition questionnaire.

Population	Urban	Rural	Total
1. Population			
Information source	Web site addresses: www.		
2. Waste legislation			
3. Waste data			
4. Environment agency			
Waste data	Tonnes per year		
5. Total municipal waste arisings per year (t/yr)			
6. Total municipal waste recycled per year (t/yr)			
7. Total municipal waste composted per year (t/yr)			
8. Total municipal waste disposed per year (t/yr)			
Waste composition	Percentage		
9. Paper and card			
10. Glass			
11. Metals			
12. Plastics			
13. Organic/biodegradable			
14. Inert			
Landfill details		Answers	
15. Is there legislation controlling landfill construction?		Yes/no	
16. What is the average size of urban landfills?		Tonnes	
17. Are the landfills capped and restored?		Yes/no	
18. How many landfills have gas flaring systems?			
CDM projects	Number	Names	CERs per year
19. Existing waste composting			
20. Existing landfill gas			
21. Proposed waste composting			
22. Proposed landfill gas			

are in sub-Saharan Africa, with none in North Africa, further demonstrating the divide that exists between the regions. Dirtiness is measured by lack of potable water and contamination of water, sewage management, waste management and air quality. It is noted that of the 10 largest cities in Africa, only the fourth largest, Addis Ababa, is in the top 25 dirtiest cities in the world. Information for Addis Ababa was requested to make a comparison against Durban, which has the same population of around 3.5 million. The population density in Durban is reported as 1513 inhabitants per square kilometer (km^2), whereas the population density in Addis Ababa is over three times greater at 5165 inhabitants per km^2. Also, Durban and South Africa are considerably more affluent than Addis Ababa and Ethiopia. South Africa is ranked 66th by the World Bank by Gross Domestic Product (GDP) with $10,109 per capita, whereas Ethiopia is ranked 155th with a GDP of $868 per capita (World Bank, 2009). The World Bank GDP ranking system includes 166 countries in total. These differences were taken in consideration in the analysis of the data acquired during the study.

3. Results and discussion

Waste data were requested for seven cities: Addis Ababa and Arba Minch, Ethiopia; Nakuru, Kenya; Arusha, Tanzania; Windhoek, Namibia; and Cape Town and Durban in South Africa. Replies were received from all contacts, with the exception of Nakuru in Kenya (i.e. an 86% response rate). The data received, as presented in Table 5, is summarized as follows:

- Population: The population for the cities ranged from a minimum of 75,000 for Arba Minch in Ethiopia to around 3.5 million for Addis Ababa in Ethiopia and Durban in South Africa.
- Information sources: web based environmental information can be sourced for Ethiopia, Namibia, South Africa and Tanzania; although the quality and extent of this information is highly variable.

Table 5
Results of the questionnaire campaign.

City	Arba Minch	Windhoek	Arusha	Cape Town	Addis Ababa	Durban
Population	74,000	300,000	359,000	3000,000	3384,000	3500,000
Information						
Legislation	Yes	–	–	Yes	Yes	Yes
Web links	No	–	–	Yes	No	Yes
EPA	Yes	–	–	Yes	Yes	Yes
Waste data						
Arisings kg/hd/year	36.5	242	531	482	91.98	369
Recycled %	No formal	(2%) informal	11.70	No formal	No formal	1
Composted %	No formal	–	None	2	No formal	4
Disposed	All	100%	88.30%	98%	100%	95%
Waste composition						
Paper and card	1.55	15	8	–	2.5	19.3
Glass	0.04	14	6	–	0.5	7.1
Metals	0.55	4	3	–	0.9	6.9
Plastics	2.61	4	5	–	2.9	17.4
Organic/biodegradable	49.46	47	65	–	60	42.5
Inert, ash	45.75	16	13	–	33.8	6.8
Landfill						
Regulations	No, dump site	–	No, dump sites	Yes	Yes but open dump sites	Yes
Average size	No landfill	–	No landfill		No landfill	2 M–17 M
Capped/restored	N/A	–	N/A	Yes	N/A	Yes
Gas flaring	N/A	None	N/A	Yes	N/A	Yes
CDM						
Existing composting	None	None	None	None	None	None
Existing landfill	None	None	None	None	None	Two
Proposed composting	None	None	None	None	None	None
Proposed landfill	None	One	None	Five	None	One

- Ethiopia has a draft Environmental Protection Proclamation and its Environment Protection Agency (EPA) web site is being developed, as yet having no data regarding waste management.
- Tanzania has a National Environmental Action Plan (NEAP) and the Tanzania National Conservation Strategy for Sustainable Development (NCSSD). The National Environmental Policy was drafted in 1997 and enacted through the Environmental Management Act of 2004. This is implemented by a national Division on Environment which seeks to apply the waste hierarchy and provide the population with waste receptacles.
- Namibia's Environmental Management Act 2007 promotes sustainable management of the environment and use of natural resources by establishing principles for decision making on matters affecting the environment including applying the waste hierarchy and regulating the disposal of waste.
- South Africa has comprehensive environmental legislation controlling waste management, which is regulated by the Department of Environmental Affairs and Tourism (DEAT).

- Waste data: The waste production data per capita for the researched African cities are highly variable and reflect the GDP of the respective countries. In Ethiopia, waste production ranges from 36.5 to 92 kg/hd/yr; for Namibia the figure is 242 kg/hd/yr; for South Africa it ranges from 369 kg/hd/yr in Durban to 482 kg/hd/yr in Cape Town; and for Arusha in Tanzania it is 531 kg/hd/yr. These figures include construction waste, which, for Durban and Cape Town, is currently significant due to infrastructure development required for the 2010 World Cup. The mean waste production for the six cities is 292 kg/hd/yr, which is similar to the results of the first questionnaire presented in Couth and Trois (2009a) and compatible with an average waste production of 230 kg/hd/yr for cities in Africa as confirmed by a review study published in Couth and Trois (2010).
- Waste composition: Table 4 shows that there is little recyclable material (4.75–6.8%, paper and card, glass, metals and plastics) in urban waste in Ethiopia and the majority of the waste is organic/biodegradable or inert. Waste composition changes within the more affluent cities in South Africa and Tanzania, with a lower percentage of inert materials and a higher percentage of dry recyclables.

  The important figure, in relation to carbon emissions, is the percentage of biogenic carbon in the waste. This ranges from 42.5% for Durban to 65% for Arusha, with a mean for five cities of 52.8%, which is comparable with a mean of 55.7% (±25% to incorporate discrepancies in the data) proposed by other studies (Cointreau, 2006; Couth and Trois, 2009a; Couth and Trois, 2010).

  This value is noticeably greater than that in developed countries (i.e. a 39% biogenic carbon content is reported for the UK) (Waste Online, 2006).
- Landfill details. Landfill sites sites in Ethiopia and Tanzania were reported as open dump sites/uncontrolled landfills. Landfill facilities in cities in Namibia and South Africa comply with minimum design standards, primarily associated with the protection of the environment from leachate and biogas. None of the landfills had active landfill gas extraction and combustion systems, with the exception of Durban and Cape Town.
- CDM projects. None of the cities have registered waste composting or landfill gas CDM projects, with the exception of Durban which has two landfill gas projects: component 1 – Mariannhill landfill (1 MW installed) and component 2 – Bisasar Road landfill (6.5 MW installed) (Strachan and Pass, 2009). However, there is considerable interest in CDM projects. There are no registered waste projects in Ethiopia on the UNEP (UN Environment Programme) CDM pipeline web site at the end of 2009, and only one registered project on reforestation. No waste CDM projects were reported as being proposed for Arusha in Tanzania although there is a registered landfill gas project in Dar es Salaam. In Namibia several CDM waste projects have been proposed, but none is currently registered. The eThekwini Municipality (Durban) has a number of registered CDM projects for the region of KwaZulu-Natal, while Cape Town has no registered waste CDM projects to date.

Although Africa contains around 15% of the world's population, it contributes for 6% of the world's GHG emissions with those in sub-Saharan Africa being less than a quarter of the global average (Table 1). However, the percentage of GHG emissions from waste management in Africa is over three times greater than those in the USA (Couth and Trois, 2009b), with the primary cause of these emissions being CH_4 in landfill gas. GHG emissions are set to increase as the population in Africa becomes more urbanized and more waste is disposed in landfills. The results of the questionnaire campaigns on waste management in African countries show that the data is very poor. Whilst all sub-Saharan countries have legislation to manage waste, resources are directed to more important issues as housing, poverty, food security and health.

This study shows that waste production is linked to the national GDP: the higher the GDP, the greater the waste production. It calculates the average waste production from African countries to be around 230 kg/hd/yr. This is about half of the waste production in developed countries. However, the average biogenic carbon content of sub-Saharan waste is around 56%, which is generally greater than the typical biogenic carbon content and combustible waste fraction in developed countries. This, coupled with the inability to develop recycling, composting, treatment and disposal systems to control emissions, makes Africa an important global contributor of GHG.

Comments on returned questionnaires stated that lack of funding is the reason for poor waste management practice in urban areas in sub-Saharan territories. In North African territories there are mechanisms for financing waste management activities based on the 'Polluter Pays' principle. For example, cities in Egypt retain 2% of the rental value from properties for the collection and disposal of waste. However, many cities in sub-Saharan Africa cannot apply such charges to residents living in poor housing. Cities such as Kampala (Uganda) and Khartoum (Sudan) are investigating privatisation of waste management activities, with the private sector generating finance to manage waste. Funding can be obtained from public and private sector stakeholders and by trading in Certified Emission Reductions (CERs) obtained through Clean Development Mechanisms (CDM) projects. It is, however, the experience of Durban in South Africa that CDM projects can take 2–4 years for final commissioning, with a subsequent pay-back period of over 3 years and 9 months for issuance of CERs, which result in up to 8 years before banks can fully recover their investment. This pay-back period is not attractive to investors in the current economic climate. Moreover, international banks/investors are less likely to fund projects in sub-Saharan countries where the political situation is unstable, and the ownership of the project may be questioned.

4. Conclusions

It is reported that waste management is often low on the agenda for officials in developing countries (Ferreira et al., 2007). Inadequate urban solid waste management is related to the restricted funding of public services and the lack of technical and human resources. The above figures show that waste production from sub-Saharan cities is clearly linked to the GDP of the country, although this link is not evident with waste compo-

sition. In Sub-Saharan countries waste is disposed primarily in uncontrolled dumps, making it difficult to control and monitor liquid and gaseous emissions.

African countries are Non-Annex 1 Parties under the Kyoto Protocol, and do not have targets to limit their GHG emissions. Where African countries make policy commitments to control their GHG emissions, they do not have finances to implement them unless these are provided by developed countries. Policy makers have two main forms of intervention to abate CO_2 emissions, namely carbon taxes and a "cap and trade" system. However, some of these schemes are not yet appropriate for developing countries, where basic waste management systems are still lacking, and reduction of carbon emissions is not a priority.

Moreover the international value of CERs post Kyoto from 2013 is unknown although there will remain a demand for CERs e.g. from EU countries under the EU Emissions Trading Scheme. The outlook for emissions reductions from African countries is unlikely to be positive unless a new international mechanism is introduced to replace the CDM and the Kyoto Protocol.

The global economy fundamentally drives climate change, and current economic strategies will need to be revised to limit the negative impact of all the above-mentioned externalities on the development of the African continent.

Acknowledgement

The authors wish to thank Mr. Grant Pearson of SLR Consulting Ltd. for his valuable review of this paper.

References

Cointreau, S., 2006. Occupational and environmental health issues of solid waste management: special emphasis on middle and lower-income countries. The World Bank Group. Urban papers. July 2006. http://wwwwds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2007/07/03/000020953_20070703143901/Rendered/PDF/337790REVISED0up1201PUBLIC1.pdf.

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

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

Couth, R., Trois, C., 2010. Carbon reduction strategies in Africa from improved waste management. May 2010. Waste Management 30 (11), 2336–2346.

DWAF, 1998. Minimum Requirements for Disposal by Landfill. Department of Water Affairs and Forestry. 2nd ed., 1998. http://www.dwa.gov.za/Documents/.

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

Globalisation and the Environment, 2008. The World's top 25 dirtiest cities. Globalisation and the Environment, March 2008. http://globalisation-and-the-environment.blogspot.com/2008/03/worlds-25-dirtiest-cities-2008.html.

IPCC, 2007. Climate Change 2007: The Physical Science. United Nations Intergovernmental Panel on Climate Change (IPCC). February 2007. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf.

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

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

UNFCCC, 2005. Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention. Framework Convention on Climate Change (UNFCCC). http://unfccc.int/resource/docs/2005/sbi/eng/18a02.pdf October 2005.

UNSD, 2008. Millennium Development Goals Report Statistical Annex 2008. United Nations Statistical Division 2008. http://mdgs.un.org/unsd/mdg/Resources/Static/Data/StatAnnex.pdf.

Waste Online, 2006. What's in your bin? May 2006. http://www.wasteonline.org.uk/resources/InformationSheets/WasteDisposal.htm.

World Bank, 2009. World Development Indicators database, World Bank, September 15, 2009. http://siteresources.worldbank.org/DATASTATISTICS/Resources/GDP_PPP.pdf.

Worldwatch Institute, 2009. 2009 State of the World, Into a Warming World; Worldwatch Institute 2009: http://www.worldwatch.org/stateoftheworld.