Greenhouse Gas Emissions Inventory for Kampala City and Metropolitan Region

Final Report

Shuaib Lwasa
Makerere University

February 2013

Executive Summary

This report presets a greenhouse gas emission inventory that was conducted as a baseline for Kampala city and 2012 as the base year. The inventory was conducted using the Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC). The GPC builds on previous protocols that include the *International Local Government GHG Emissions Analysis Protocol* (ICLEI), *Draft International Standard for Determining Greenhouse Gas Emissions for Cities* (UNEP/UN-HABITAT/WB), *GHG Protocol Standards* (WRI/WBCSD), *Baseline Emissions Inventory/Monitoring Emissions Inventory methodology* (EC-CoM JRC), and *Local Government Operations Protocol* (ICLEI-USA). The baseline results are estimates of community-based emissions attributed to the 196 sq km of surface area of Kampala city and the city region that spans an area of 941.2 sq km. The population estimates of Kampala city at base year stand at 1.72 m and for the city-region 3.56 m adjusted from 2007 data. The total CO_2e emissions stand at 313,320 tCO_2e distributed as 53,178.5 tCO_2e from stationary units, 26,407.3 tCO_2e from mobile units, 203,771 tCO_2e from wastes, 29,926.4 tCO_2e from Industrial Processes and Product uses and 35.5 tCO_2e from Agriculture, Forestry and Land Use. Using the adjusted population of the city, the percapita emission stands at 0.18216 tCO_2e for in-boundary population and 0.08801 tCO_2e for combined in-boundary and out-boundary population.

Emissions are calculated based on activity data acquired from multiple sources and checked for minimization of overestimate and underestimate. Activity data was acquired from national statistical databases, agency databases, survey databases for the city and city-region as well as field based interviews for a selected sample of informal activities in the city. Informal activity data is based on sector-based activities of production and service provision in economic zones of the city including small-medium-large scale industrial-commercial areas within and out of the city adjusted to the base year estimates. Emission factors for the different sectors are applied to calculate in-boundary and out-boundary emissions to establish the relationships between city-specific and city influenced emissions. Estimates of CH_4 and N_2O are calculated as CO_2 equivalents using the standard warming factors. A summary of the results by major sector (*figure 1*) and subsector (*figure 2*) are shown in the figures below;

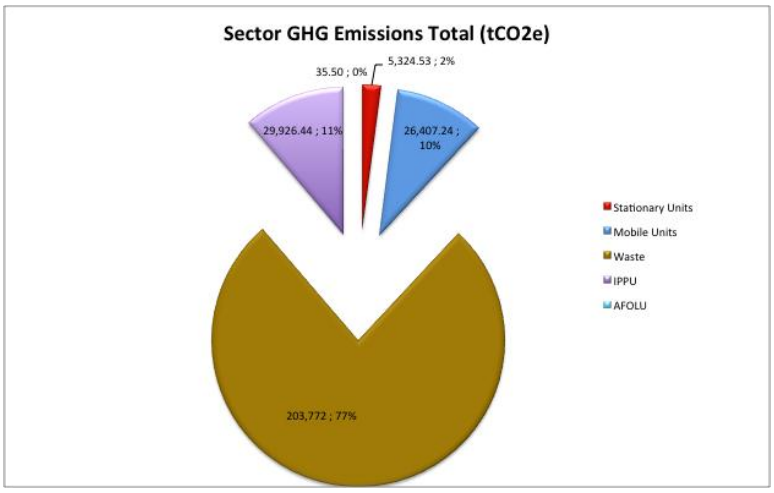


Figure 1; Total Emissions by Sector 2012

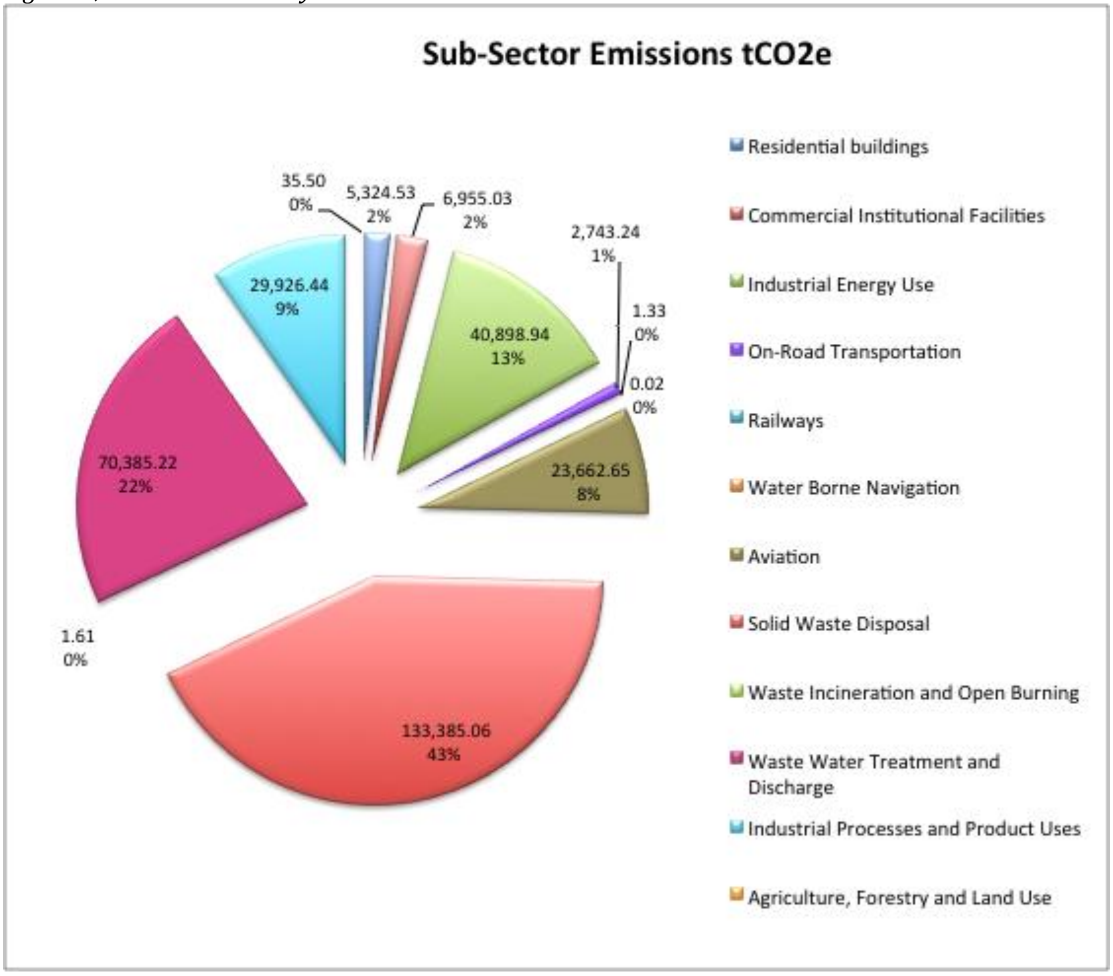


Figure 2, Total emissions by sub-sector 2012

Results indicate that waste sector in general specifically solid waste and waste treatment subsectors rank first and second representing 43% and 22%. Industrial energy use ranks third with 13% of the emissions while 9% of the total emissions are from residential buildings. This distribution is related to the population and the different practices for waste and wastewater treatment, which are characterized by pit-latrines and scattered dumping grounds for solid wastes. The emissions from wastes also relate to the chemical transformation characterized by methane from decomposing wastes. The summary results provide insight into the lifecycle of materials in the city as well as pathways for emissions generation. In that respect the distribution of emissions by sector also gives insight into entry points for mitigation planning. The city's plans for a low-carbon city will be informed by the baseline data. In conclusion, the GPC provides an opportunity to estimate in-boundary emissions, which requires detailed activity data for the geographic units. This bounding is useful in attributing the estimates to the communities where activities are undertaken but it also has challenges including the availability and reliability of detailed data. In cities where databases are non-existent or not up-to-date, the activity data is adjusted on basis of assumptions in order to calculate sector-based emissions. Thus the GPC requires being adapted to the specific city as some sub-sectors and or categories may not be applicable to the community.

1. Introduction

Several cities have been reporting greenhouse gas emissions in the last decade [1,2]. This has been motivated by the need to develop city mitigation plans, which require baseline data for targeting and benchmarking [3]. This emissions inventory was carried out following the guidelines of the Global Protocol for Community-Based Emissions released in 2012, which emphasizes community scale emissions calculated using activity data within and outside the geopolitical boundaries [4]. Emission factors for the different categories of the fuels and sources are utilized to calculate disaggregated emissions of Kampala city and the city-region [5]. The city-region is the geographic extent as defined in the Kampala Physical Development Plan with in which recent surveys on transportation and energy use have been conducted [6]. Emissions estimates are based on both consumption and production activities with accounting taking into considerations required adjustments for non-double counting. The GPC's inclusion in activity data of community-scale emission sources enabled collection and calculation of emissions from both formal and informal economic sources. A summary of the emissions is presented using the tables for reporting as provided for in the GPC [7].

2. Inventory Objective

There are several energy consuming activities responsible for emissions in the city though there has not been a geographically focused inventory of the greenhouse gas emissions. As noted in the urban vulnerability assessment report, the city relies heavily on fossil fuel for transportation, electricity generation, domestic uses and industrial sectors [8,9]. The major objective of the inventory is to profile the energy consuming activities of the city on basis of which *conduct a GHG inventory for Kampala* that includes informal and formal activities. The second objective is to *formulate recommendations for emissions reduction and mitigation* in the city.

3. Methods and materials

Future impacts of climate change on cities are projected to increase and thus mitigation is necessary but that requires an understanding of the sources of and estimation of GHG emissions in cities. The GHG inventory is a critical pre-requisite for policy support and response toward mitigation but has to be supported by strategy development and implementation [1,10]. The inventory was conducted with the Global Protocol for Community-Scale Greenhouse Gas Emissions which is adapted from various frameworks based on internationally accepted tools for quantifying the GHG emissions attributable to cities and local regions [7]. The inventory of GHG emissions in Kampala spins off a broad assessment of vulnerability to climate change in which mitigation strategies were identified as necessary and would couple with adaptation measures. The inventory utilizes the GPC framework estimating emissions from three levels and data adjusted to calculation of the emissions. These are *Scope 1*; GHG emissions that occur within the territorial boundary of the city or local region; in the context of Kampala, the city is administratively limited to the 196 sq km surface area including the water body based on the most recent Kampala Physical Development Plan boundaries that were agreed with both regional governments and Kampala Capital City Authority (KCCA) [6]. *Scope 2* covers the indirect emissions that occur outside of the city boundary as a result of activities that occur within the city, limited to only electricity consumption which generated from thermal plants some of which are in the city-region. The city region is the area outside the city administrative boundaries covering and estimated 941 sq km around the city's administrative boundaries, which was defined in the recent Kampala Physical Development Plan. For this category emissions were also calculated for agriculture, forestry and land use changes in the peri-urban zones of the region focused on biomass consumption [11]. *Scope 3*; is any other indirect emissions and embodied emissions that occur outside of the city boundary, as a result of activities of the city. In this category of emission sources, marine and air transport were the focus as they apply to Kampala with estimates of activities originating from the city that generate emissions associated with these modes of transportation.

3.1. Data Sources

Data were collected from various sources in all activities included in the calculations. Databases from agencies responsible were collected and some of it adjusted using the recent survey data from KCCA mapping and physical planning exercise. The table below shows the different data sources and adjustments made for the calculations.

Data required	Source	Adjustments
ENERGY		
Stationary Combustion	ESKOM, UBOS, ERA	Data on thermal plants and hydro units were collected and adjusted to estimated production capacity and fuel usage
Electricity (incl. T&D losses	Electricity Transmission Company, UMEME	Transmission agency data and end user data used in estimates
Commercial & Institutional	KCCA data on buildings	Data on buildings adjusted using recent mapping by type within KCCA boundaries collaborated with UMEME data some of which was georeferenced
Residential	KCCA data on buildings	Data adjusted using recent city-wide household survey to estimate buildings within and outside KCCA boundaries
Manufacturing Industries & Construction	KCCA mapping data on buildings, UMA and UIA lists by type	Data collaborated from Uganda Investment database with recent mapping to estimate industrial activity within KCCA boundaries

Other		
Mobile Combustion	UNRA, weighing bridge data	Traffic counts by type acquired from UNRA, URA and collaborated with UBOS data
Road transportation: LDVs	UBOS transportation data	Data was insufficient but some collected from UBOS and UNRA. It was largely aggregated to national and vehicle types
Road transportation: trucks	UBOS, KCCA, UNRA, weighing bridge data	Data of trucks like LDV's was aggregated and estimates conducted using the transportation survey in Kampala of 2011 on trips by type
Road transportation: other	KCCA transportation survey	Utilized the trip by mode data from the KCCA transportation survey
Railways	UBOS, Rift Valley Railways	Data from UIA and GIS database eon length within KCCA boundaries
Domestic aviation	CAA data	Data from UBOS though insufficient in terms of details fro estimate of activities originating from city
International aviation	CAA data	Data collected from Civil Aviation Authority as it was easier for them than domestic data
Domestic marine	Rift Valley Railways	Collected from Rift Valley Railways but since it's a relative new company, it was mainly recent data points with gaps
INDUSTRIAL PROCESSES		KCCA data on properties and recent surveys. Though not very representative and the level of aggregation was high to attribute proper estimates by category
AFOLU	KCCA mapping data	Determination of emission using time series land use change data from the recent mapping of KCCA and city-region. Additional data acquired from recent scientific study
WASTE		
Solid waste disposal on land	KCCA landfill data	Data collected at weighing bridge of KCCA landfill and adjusted with current statistics of wastes processed by

		individuals and amounts left on dumping sites as well as homes and business establishments
Wastewater handling	NWSC data on treated water	National Water and Sewerage Corporation provided recent and historical data from the treatment plant
Waste incineration	Ministry of health incineration data	Ministry of health data and a few industries that have incinerators

3.2. Data on fuel

Data specific to fuel imports and usage by activity was collected from various sources and published documents. The sources are indicated below and adjustments on the data using the GPC calculations.

ENERGY		
Electricity (on-site renewable)	URA fuels imports data	Adjusted using emission factors and calculated to CO_2e
Electricity (grid	ESKOM generation data and transmission data	Adjusted using emission factors and calculated to CO_2e
Natural gas TJ t CO_2 e / TJ	URA imports data	Adjusted using emission factors and calculated to CO_2e
Fuel oil TJ t CO_2 e / TJ	URA imports data	Adjusted using emission factors and calculated to CO_2e
Gasoline TJ t CO_2 e / TJ	URA imports data	Adjusted using emission factors and calculated to CO_2e
Diesel TJ t CO_2 e / TJ	URA imports data	Adjusted using emission factors and calculated to CO_2e
Jet Fuel TJ t CO_2 e / TJ	URA imports data, collaborated with CAA data	Adjusted using emission factors and calculated to CO_2e
Marine Fuel TJ t CO_2 e / TJ	URA imports data	Adjusted using emission factors and calculated to CO_2e
INDUSTRIAL PROCESSES		
WASTE		
Solid waste disposal on land kt t CO_2 e / kt	KCCA landfill data	Adjusted using emission factors and calculated to CO_2e
Solid waste disposal onsite of generation kt CO_2e/kt	KCCA data on survey	Adjusted using percapita generation and emission factors of decomposition to CO_2e
Wastewater handling kt BOD t CO_2 e / kt	NWSC data	Adjusted using emission factors and calculated to CO_2e
BOD	Landfill leachates data, water treatment plant data	Adjusted using emission factors and calculated to CO_2e

Waste incineration kt t CO_2 e / kt	Ministry of health incineration data	Adjusted using emission factors and calculated to CO2e
Human waste managed using pit latrines	KCCA data	Adjusted using percapita generation and emission factors of decomposition to CO_2e
Methane from livestock management	KCCA data colloborated with ministry of Agriculture and Animal Industries data	Adjusted using livestock emission factors by type of decomposition to CO_2e
AFOLU9 add AFOLU activity data as appropriate)	KCCA land use data	Two event land use snapshots provided an estimate of change and deforestation within boundary of city

3.3. Upstream (Embodied) Greenhouse Gas Emissions

ENERGY		
Electricity (on-site renewable) GWh t CO_2 e / GWh	ESKOM power generating company	Adjusted using emission factors and calculated to CO2e
Electricity (grid) GWh t CO_2 e / GWh	ESKOM and Electricity Transmission Company Ltd	Adjusted using emission factors and calculated to CO2e
Natural gas TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
Fuel oil TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
Gasoline TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
Diesel TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
Jet Fuel TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
Marine Fuel TJ t CO_2 e / TJ	URA imports data and estimates used in Kampala	Adjusted using emission factors and calculated to CO2e
WATER ML t CO_2 e/ ML	NWSC data from the treatment plants and city-region systems	Adjusted using emission factors and calculated to CO2e
BUILDING MATERIALS		
Cement Kt t CO_2 e / kt	URA imports, UMA data	Adjusted using emission

	on local producers	factors and calculated to CO2e
Steel Kt t CO_2 e / kt	URA imports	Estimates based on housing stock increment in the city
Bricks Kt t CO_2 e / kt	From sample of building material sales data	Estimates of bricks produced based on increment in housing stock within city
FOOD		
Cereals Kt t CO_2 e / kt	Food inflows into city KCCA, Ministry of Agriculture	Adjusted using emission factors and calculated to CO2e
Fruits Kt t CO_2 e / kt	Food inflows into city KCCA, Ministry of Agriculture	Adjusted using emission factors and calculated to CO2e
Meat Kt t CO_2 e / kt	Food inflows into city KCCA, Ministry of Agriculture	Adjusted using emission factors and calculated to CO2e
Seafood Kt t CO_2 e / kt	This was found to be negligible since there are few sea food specialized restaurants in the city	
Dairy Kt t CO_2 e / kt	Food inflows into city KCCA, Ministry of Agriculture, Dairy Authority	Adjusted using emission factors and calculated to CO2e

4. Measuring GHG emissions

The principles of GHG inventory are adhered to in the inventory but there are data gaps and quality issues, which are specified, in the reporting summary tables. This GHG inventory utilizes the GPC and is in line with the revised IPCC [12] emission guidelines and emission factors. However emissions related to specific activity sectors such as land use change and deforestation associated with urbanization were calculated basing on adjusting scientifically derived emissions based on available peer-reviewed literature [11,13]. Measurability, accuracy, relevance, consistence, transparence and completeness principles are followed but this is to a varied degree because of the multiplicity of activities and energy mix that made it challenging to estimate fuel consumption and emission of the activities. Energy mix in stationary combustion activities such as residential, industrial process is complex that disaggregated data would be useful in high accurate estimates but data at the level of disaggregation was not available or insufficient. For the informal sector, a sample of activities in economic zones was taken and average energy utilization estimated from usage data. These averages were liked to the data on industrial establishment, which was available but adjusted to the base year. Major energy sources are electricity; fuel wood, charcoal and other biomass in form of saw dust or husks. Because of frequent power load shedding and blackouts, commercial entities as well as residential building generate power with combustion of several fuels most of which are imported. Data on the additional fuel usage was collected and monthly averages calculated to estimate emissions from combustion to generate power on-site.

5. Materials and methods

Household Survey data; a recent household survey was conducted as part of the Kampala physical development plan formulation [6]. This was based on a 3000 sample of households with data on basic housing parameters, transport modes, trips and destination, energy use and vehicle-kilometer coverage. The sample comprises of households within the boundary of Kampala as well as outside the boundary of Kampala. The Kampala boundary of 196 sq km is considered in this inventory as the community boundary on basis of which all in-boundary estimates are calculated. The out-boundary community geographically covers an area of 941.2 sq km engulfing the adjacent satellite towns and rural settlements in the region as shown in *Map 1 below*. This extends from 20 miles northwards stretching to Entebbe airport in the south. The survey included informal and formal business enterprises especially transportation by motorcycles which data supported calculations of emissions associated with mobile combustion.

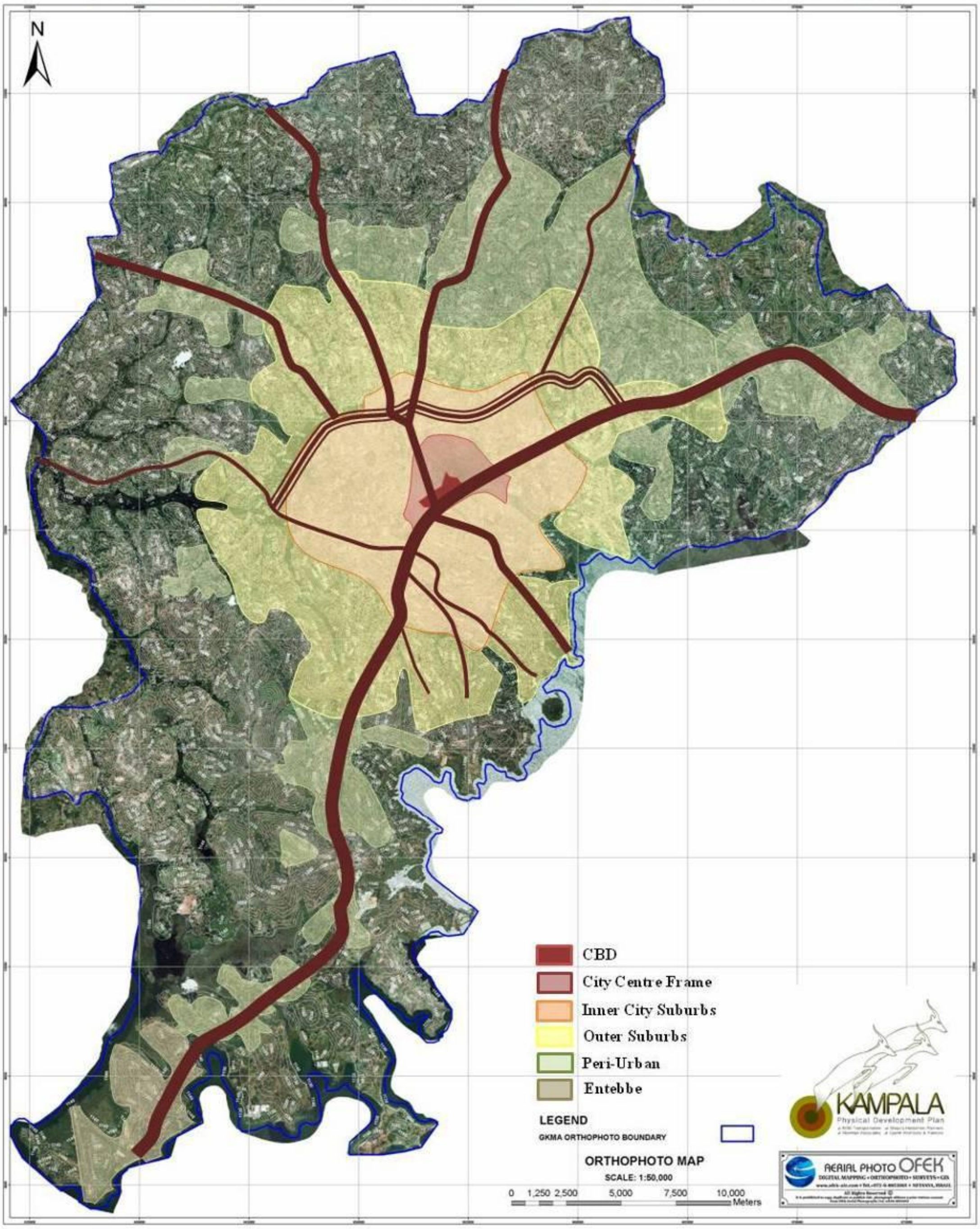
Statistical abstract, business register and demographic and household survey; the inventory also utilized data from the statistical abstract published in 2005 by UBOS adjusted using the demographic and household survey of 2009[14]. In addition the business register of 2005 was reviewed and data on Kampala and the region utilized for estimates. The publication has disaggregated data on commercial entities, industrial activity, energy generation, energy use and other activities like livestock raring, which have been included in the inventory to account for methane and nitrous oxide emissions. An inclusion not provided for in the GPC but a common practice is the use of pit latrines in managing human wastes. The data sources provided basis for calculation of emissions associated with managing human wastes.

Informal sector data; a sample of 81 informal sector activities categorized as; small and medium scale industries in recycling, food processing, retail trading, recharging services and restaurants were selected randomly from the economic zones within and without the geographic extent of the community. Data was collected on source energy, type, average use and adjusted to standard units, monthly averages and annual averages. This data is utilized to estimate the emissions from the informal sector.

Mapping data; the inventory made use of the recent mapping exercises under the Kampala physical development plan in which building footprints were used to estimate number of structure by category when overlaid with land use map. The land use map is based on 2011 imagery and the buildings. This data is less accurate for emissions estimates because even with overlays on land use data, it was difficult to estimate floor area since some of the structures are storied while many are single story.

6. Kampala's setting and development trajectory

Kampala City is a described as a primate city in Uganda due to its shear share of the urban population and dominance of urban functions. The city is geographically situated 0^{o}19'North latitude and 32^{o}25' East longitude [11,15]. The city has recently emerged as an engine of growth for the country registering a national average economic growth rate of 7.4% in the last 7 years [6]. Kampala's commercial and industrial activities contribute significantly to GDP of the country. Apart from being the political hub of the country, Kampala is the industrial but also educational center of the country attracting various activities that are energy intensive. The city is administratively comprised of five lower municipalities responsible for local planning though resource allocation and implementation is centralized at the city level with the new Act. These municipalities include Kampala Central Division, Kawempe Division, Makindye Division, Nakawa Division and Lubaga Division. The national census in 2002 estimated the population of the city at 1,189,142. This figure was adjusted to 1,420,200 in 2008 following the national demographic and health survey of 2007. In 2011 the mid-year population of the city was estimated at 1,659,600 (UBOS 2009) and the recent survey preceding the Kampala Physical Development Plan estimates the population at 1.72 million within the city boundary and 3.56 m in the city region. A range of activities in the city that underpin energy use include industries of different scales, electricity generation, residential buildings and the skewed reliance on biomass energy particularly wood fuel and charcoal. But future trajectories indicate growth in all sectors and limited awareness nor strategies to reduce carbon footprint of the city has been raised.



Map 1: Kampala City and City-Region Source KPDP 2012

7. GHG Emission Summary

				Gases(tones)			
GHG Emission Sources	**IPCC Code**	**Scope**	**Accounting Approach**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**
Stationary Units							
Residential Buildings							
Direct Emissions	1A4b	Scope 1	In-Boundary	250.57	0.4	0.00	366.8
Energy Indirect Emissions		Scope 2	In-Boundary	3478.063115	4.77	0.06	4957.7
Commercial/Institutional Facilities(including energy consumption in street/traffic lights and treatment facility operations)							
Direct Emissions	1A4a	Scope 1	In-Boundary	1,217.39	0.55	0.006905968	1386.8
Energy Indirect Emissions		Scope2	In-Boundary	4,088.59	4.77	0.06	5568.2
Energy Generation(includes generation of electricity, heating and/or cooling)							
Direct Emissions	1A1a	Scope 1	In-Boundary	797,821			797820.7
Energy Indirect Emissions		Scope 2	In-Boundary	10972.5			10972.5
Energy Use in Industrial Activities							
Direct Emissions	1A1b-c+1A2+1A5+1A4C	Scope 1	In-Boundary	797,821			797820.7
Energy Indirect Emissions		Scope 2	In-Boundary	10972.5			10972.5
Mobile Units							
On-Road Transportation(Cars, LDV,HDV/Buses, Others)							
Direct Emissions	1A3b	Scope 1	In-Boundary	2229.946305	0.000874408	0.006517772	2230.4
Energy Indirect Emissions		Scope 2	In-Boundary	512.88765			512.9
Railways (including urban metro/rail transport systems)							
Direct Emissions	1A3C	Scope 1	In-Boundary and Proportional Responsibility	1.268498623	0.00019247	2.88705E-09	1.3

Energy Indirect Emissions		Scope 2	In-Boundary and Proportional Responsibility	0.000747508	1.1342E-10	1.7013E-09	0.0
Water-Borne Navigation							
Direct Emissions	1A3dii	Scope 1	In-Boundary	0.02	2.49995E-06	3.74992E-08	0.0
Energy Indirect Emissions		Scope 2	In-Boundary				0.0
Indirect Emissions from Inter-City Domestic Marine Trips	1A3dii	Scope 3	Origination				0.0
Indirect Emissions from International Marine Trips	1A3dii	Scope 3	Origination				0.0
Aviation							
Direct Emissions	1A3aii	Scope 1	In-Boundary				0.0
Energy Indirect Emissions		Scope 2	In-Boundary	23658.81135	0.012115465	0.004038488	23662.7
Indirect Emissions from Inter-City Domestic Flights(LTO and Cruise)	1A3aii	Scope 3	Origination				0.0
Indirect Emissions from Inter-City International Flights(LTO and Cruise)	1A3ai	Scope 3	Origination				0.0
Off-Road							
Direct Emissions	1A3eii	Scope 1	In-Boundary				0.0
Energy Indirect Emissions		Scope 2	In-Boundary				0.0
Waste							
Solid Waste Disposal							
Future Indirect Emissions from Community Generated Waste Landfilled in the Community in the Analysis-Year	4A	Scope 3	Proportional Responsibility	96.50857438	186.72	0.73	57993.5
Future Indirect Emissions from Other Communities` Waste Landfilled in the Community in the Analysis-Year	4A	Scope 3	Proportional Responsibility	19.30	37.34	0.15	11598.7
Future Indirect Emissions from Community Generated Waste Landfilled outside the Community in the Analysis-Year		Scope 3	Proportional Responsibility	106.1594318	205.3869231	0.797692918	63792.9
Biological Treatment of Waste							
Direct Emissions from Community Generated Waste	4B	Scope 1	Proportional Responsibility				0.0
Direct Emissions from Communities` Waste	4B	Scope 1	Proportional Responsibility				0.0

Treatment							
Emissions from Community Generated Waste Treated Outside the Community		Scope 3	Proportional Responsibility				0.0
Incineration and Open burning.							
Direct Emissions from Community Generated Waste Incineration	4C	Scope 1	Proportional Responsibility	0.230080506			0.2
Direct Emissions from Communities` Waste Incineration	4C	Scope 1	Proportional Responsibility				0.0
Emissions from Community Generated Waste Incinerated Outside the Community		Scope 3	Proportional Responsibility	1.380483039			1.4
Waste Water Treatment and discharge							
Direct Emissions from Community Generated Wastewater Treatment	4D	Scope 1	Proportional Responsibility		42.228	16.6175	13439.6
Direct Emissions from Communities` Wastewater Treatment	4D	Scope 1	Proportional Responsibility	14.399	183.6	0.7225	56945.6
Emissions from Community Generated Wastewater Treated Outside the Community		Scope 3	Proportional Responsibility				0.0
IPPU							
Industrial Processes and Product Uses							
Direct Emissions From Industrial Processes	2A+2B+ 2C+2E	Scope 1	In-Boundary		47.58	31.43	15408.6
Direct Emissions From Product Use	2D+2F+ 2G+2H	Scope 1	In-Boundary		44.83	29.61	14517.9
Additional Sources to 2012 Standard							
Stationary Units							
Stationary Units indirect Emissions							0.0
Mobile Units							
Mobile Units Other Indirect Emissions							0.0
Waste							**0.0**
Waste Other Indirect Emissions							0.0
IPPU							
IPPU Other Indirect Emissions							0.0
AFOLU							
AFOLU Direct Emissions	3	Scope 1		6.69			6.7
AFOLU Other Indirect		Scope 3		28.81			28.8

Emissions							
Fugitive Emissions							
Direct Emissions	1B	Scope 1					0.0
Fugitive Other Indirect Emissions		Scope 3					0.0
Other Emissions							
Other Direct Emissions		Scope 1					0.0
Other Energy Indirect Emissions		Scope 2					0.0
Other Indirect Emission		Scope 3					0.0

8. Aggregate GHG Emissions

Sector	Sector Total(tCO_2e)	Subsector	Subsector Total(tCO_2e)	Subtotal (tCO_2e)	Gases			GHG Emissions Sources	GPC No.	(Notation Keys) Choice	Explanation
					CO_2	CH_4	N_2O				
		Residential buildings	366.83		250.57	116.16	0.10	Stationary Units Residential Direct Emissions (Scope 1)	I.1.i		
Stationary Units	5324.534123		4957.70		3478.063	1478.37	1.27	Stationary Units Residential Energy indirect Emissions (Scope 2)	I.1.ii		
		Commercial Institutional Facilities	1386.80		1,217.39	169.26	0.15	Stationary Units Commercial/Institutional Facilities Direct Emissions (Scope 1)	I.2.i		
			5568.23		4,088.59	1,478.37	1.27	Stationary Units Commercial/Institutional Energy indirect Emissions (Scope 2)	I.2.ii		
		Energy Generation	10972.50		10972.5			Stationary Units Energy Generation Energy indirect Emissions (Scope 2)	I.3.iii		
		Industrial Energy Use	15408.58		797,821			Stationary Units Industrial Energy Use Direct Emissions (Scope 1)	I.4.i		
			14517.86		10972.5			Stationary Units Industrial Energy Use Energy indirect	I.4.ii		

								Emissions (Scope 2)			
Mobile Units	26407.24101	On-Road Transportation (Cars, LDV, HDV Buses, Others)	2230.35		2229.946305	0.271066514	0.136873218	Mobile Units On-Road Transportation (Cars, LDV, HDV Buses, Others) Direct Emissions (Scope 1)	II.1.i		
			512.89		512.88765			Mobile Units On-Road Transportation (Cars, LDV, HDV Buses, Others) Energy Indirect Emissions (Scope 2)	II.1.ii		
								Mobile Units Railway (Including Urban Metro/Rail Transportation Systems) Direct Emissions (Scope 1)	II.2.i		
		Railways (Including Urban Mechanical Transportation Systems)	1.33		0.000747508	3.51602E-08	3.57273E-08	Mobile Units Railway (Including Urban Metro/Rail Transportation Systems) Energy Indirect Emissions (Scope 2)	II.2.ii		
			0.00		0.02	0.00	0.00	Mobile Units Water Borne Navigation Direct Emissions (Scope 1)	II.3.i		
		Water Borne Navigation	0.02					Mobile Units Water Borne Navigation Energy Indirect Emissions (Scope 2)	II.3.ii		

			0.00					Mobile Units Water Borne Navigation Indirect Emissions From Inter-City Domestic Marine Trips (Scope 3)	II.3.iii		
								Mobile Units Water Borne Navigation Indirect Emissions From International Marine Trips (Scope 3)	II.3.iv		
		Aviation	0.00					Mobile Units Aviation Direct Emissions (Scope 1)	II.4.i		
			23662.65		23658.81135	3.755794234	0.084808257	Mobile Units Aviation Energy Indirect Emissions (Scope 2)	II.4.ii		
								Mobile Units Aviation Energy Indirect Emissions From Inter-City Domestic Flights (LTO and Cruise)(Scope 3)	II.4.iii		
								Mobile Units Aviation Energy Indirect Emissions From Inter-City International Flights (LTO and Cruise)(Scope 3)	II.4.iv		
								Mobile Units Off-Road Direct Emissions (Scope 1)	II.5.i		

		Off-Road						Mobile Units Off-Road Energy Indirect Emissions (Scope 2)	II.5.ii		
Waste	203771.8945	Solid Waste Disposal	57993.51		96.50857438	57,881.77	15.23	Waste Solid Waste Future Indirect Emissions From Community Generated Waste Landfilled in the Community in the Analysis Year (Scope 3)	III.1.i		
			11598.70		19.30	11,576.35	3.05	Waste Solid Waste Disposal Future Indirect Emissions From Community Generated Waste Landfilled Outside the Community in the Analysis Year (Scope 3)	III.1.iii		
			63792.86		106.1594318	205.3869231	0.797692918	Future Indirect Emissions from Community Generated Waste Landfilled outside the Community in the Analysis-Year	III.2.i		
								Waste Biological Treatment of Waste Direct Emissions from Community Generated Waste (Scope 1)			

		Biological Treatment Of Waste							Waste Biological Treatment of Waste Emissions from Community Generated Waste Treated Outside the Community (Scope 3)	III.2.iii		
		Waste Incineration and Open Burning	0.23		0.230080506				Waste Incineration and Open-Burning Direct Emissions from Community Generated Incineration (Scope 1)	III.3.i		
			1.38		1.380483039				Waste Incineration and Open-Burning Emissions from Community Generated Waste Incinerated Outside the Community (Scope 3)	III.3.iii		
		Waste Water Treatment and Discharge	70385.22			13090.68	348.9675		Waste Water Treatment and Discharge Direct Emissions from Community Generated Waste Water Treatment (Scope 1)	III.4.i		
			0.00		14.399	183.6	0.7225		Waste Water Treatment and Discharge Emissions from Community	III.4.iii		

								Generated Waste Water Treated Outside the Community (Scope 3)			
	29926.44348		29926.44		0	14,748.61	659.97	IPPU Direct Emissions from Industrial Processes (Scope 1)	IV.1.i		
IPPU		Industrial Processes and Product Uses			0	44.82594961	29.61040982	IPPU Direct Emissions from the Product Use (Scope 1)	IV.1.ii		
		Total Community Emissions (tCO_2e) by 2012 Accounting Standard(For Benchmarking)	313,284								
	Direct Emissions Accounted for Elsewhere							Stationary Units Energy Generation Direct Emissions (Scope 1)	I.3.i	IE-indicated Elsewhere	Accounted Under Energy Indirect Emissions (Scope 2)
								Waste Solid Waste Disposal Future Indirect Emissions From Community Generated Waste Landfilled Outside the	III.1.ii	IE-indicated Elsewhere	Accounted in Inventories of those Communities Who Import

								Community in the Analysis-Year (Scope)			Waste
								Waste Biological Treatment of Waste Direct Emissions From Other Communities` Waste Treatment (Scope1)	III.2.ii	IE-indicated Elsewhere	Accounted in Inventories of those Communities Who Import Waste
								Waste Incineration and Open Burning Direct Emissions from Other Communities` Waste Incineration (Scop1)	III.3.ii	IE-indicated Elsewhere	Accounted in Inventories of those Communities Who Import Waste
								Waste Water Treatment and Discharge Direct Emissions From Other Communities` Waste Water Treatment (Scope 1)	III.4.ii	IE-indicated Elsewhere	Accounted in Inventories of those Communities Who Import Waste
	Optional							Stationary Units Indirect Emissions (Scope 3)	V.1.i		
								Mobile Units Other Indirect Emissions (Scope 3)	V.2.i		
								Waste Other Indirect Emissions (Scope 3)	V.3.i		
								IPPU Indirect Emissions (Scope 1)	V.4.i		

AFOLU	6.694993691							AFOLU Direct Emissions (Scope 1)	V.5.i		
	28.80563952		35.4566					AFOLU Other Indirect Emissions (Scope 3)	V.5.ii		
								Fugitive Emissions Direct Emissions (Scope 1)	V.6.i		
								Fugitive Other Indirect Emissions (Scope 1)	V.6.ii		
								Other Direct Emissions (Scope 1)	V.7.i		
								Other Energy indirect Emissions (Scope 2)	V.7.iii		
								Other Indirect Emissions(Scope 3)	V.7.iii		
	Aggregate tCO_2e by Scope		tCO_2e Scope-1	183,497							
			tCO_2e Scope-2	36,531							
			tCO_2e Scope-3	93,256							

9. Uncertainty, Quality issues and data gaps

The multiple sources of data and time when data were collected are largely the major sources of uncertainties of emissions [7,10,16]. As indicated in materials used in the inventory, there are three major data sources. These include the demographic and health survey, the business register and the survey conducted before preparation of the Kampala Physical Development Plan 2011/2012. The enumeration units differ slightly as well as the samples that were determined using different methods and are of differing sizes. This is coupled with the varied scales at which activities are conducted in the city that makes it difficult for accurate estimates. For example, residential and industrial buildings energy use depends on a mix that includes onsite generation using diesel fuels. The intensities and usage data differs greatly from neighborhood to another as well as at household level. Data on housing though available from recent satellite imagery extraction has the challenge of disaggregating housing units by type to make accurate estimates of energy consumption. The major source of stationary units activity data, which was utilized in the estimates is the survey that has sample size and sampling procedure, which wasn't designed for inventorying emissions. But there are also uncertainties about the sampling and representation of informal commercial activities as well as institutions whose energy use is varied due the scales of operations. Generally there are uncertainties around averages derived from the data on these sub-categories. Data on industry and manufacturing is the most scanty and comparatively less reliable [5]. This data mainly comes from Uganda Investment Authority, which licenses businesses but does not keep up to date data on functional industries. Whereas reliability of transportation data is relatively high though energy use is varied as established during the survey of informal activities. Thus in general uncertainties in that recent data may well contribute to $\pm 15\%$ as colloborated with the sample survey of the informal sector.

10. Mitigation Options

Given the proportional emissions estimates by sector, there are mitigation opportunities with a range of options. The options are related to infrastructure development in the city that is yet to be built. The waste sector is by far the largest emitter according to the inventory and thus mitigation options exists in the use, reuse and rechanneling of waste-laden energy. The options can occur from household to citywide scales ranging from energy briquettes, bioenergy generation, alternative energy use, sustainable biomass use using conservation technology and hybrid systems that can recover energy from wastes. Urban infrastructure and mobility are also major emission sources in Kampala based on the inventory. Options for low-carbon infrastructure include off-grid energy systems, decentralized systems for water-sewerage-energy infrastructure that leverage local resources and may reduce the energy used for pumping. Buildings and building technology options exist ranging from revision of building codes, green rating and energy saving technologies. 'Low-hanging' fruit options for transportation are underway for piloting a Bus-rapid transit preceded with a feasibility study that incorporates Non-motorized transport [17].

Transportation related emissions are also high and likely to increase with improvement in roads as well as rise in private modes of transport within the city-region. This is explained by several factors including, mode, vehicle-kilometers traveled, energy use and number of trips per day per person for those who access vehicles. In respect to material flows especially biomass and nutrients, options exist in recycling for multi purposes including utilization for food production, energy, building and enhancing ecosystem services that offer co-benefits of mitigation that potentially link with adaptation. Urban form and spatial configurations of the city is unsustainable largely due to the sprawled nature of urban development that hikes costs of infrastructure delivery as well as associated energy use. There is a potential to enhance ecosystem services for resource efficient settlements if land use planning and implementation starts to check the sprawl nature of development in the region and enables different spatial configurations. This is because the city is at a stage where the strategic spatial planning is underway and if implemented can be a vehicle for mitigation [19–22]. Options include urban patterns with green belts, mixed-use, compact development and infrastructure-led city development that are less carbon intensive. These strategies have a potential for reducing embodied and indirect emissions.

11. Conclusion

Solid waste wastewater treatment has the highest emissions representing 43% and 22% of the total emissions. Stationary units emissions are high representing 13% of total emissions but with a potential to increase as more buildings are being constricted. Industrial energy use follows with 13% of the emissions while 9% of the total emissions are from residential buildings. In respect to scope of the inventory, scope 2 activities emit more than scope 1 and scope 3. The total community emissions under scope 3 are influenced by mobile combustion out side the boundary and particularly aviation. The percapita emissions for the population in the city is lower than the percapita for the city-region even when the population is split by 50% between the city and the environs. This is related to scope 3 of the activity and calculated emissions. A number of mitigation options have been identified for Kampala including urban infrastructure specific measures, measures for buildings and transportation but perhaps the spatial development framework if designed and implemented with low-carbon targets offers the long term emissions reduction entry point.

References

1) Uganda Bureau of Statistics, 2007, Report on the UGANDA BUSINESS REGISTER 2006/7, Kampala, www.ubos.org

2) Kampala Capital City Authority, 2012, Updating Kampala Structure Plan and Upgrading the Kampala GIS Unit , Final Report, Kampala, November 2012

3) Uganda Bureau of Statistics, 2009, Demographic and Health Survey, Kampala, www.ubos.org

4) Uganda Bureau of Statistics, 2004, Statistical Abstract, Kampala, www.ubos.org

5) Weisz, H., and J. K. Steinberger. "Reducing Energy and Materials Flows in Cities." Current Opinion in Environmental Sustainability 2, no. 3 (2010): 185–192.

6) Academy of Science, South Africa. Towards a Low Carbon City: Focus on Durban. Pretoria, South Africa: Academy of Science, South Africa, 2011.

7) Yunus Arikan Rishi Desai, Jonathan Connor, Alden Feldon, Amanda Eichel, Brooke Russell, Jonathan Dickinson, Dan Hoornweg, Pankaj Bhatia, Wee Kean Fong, Ian Shearer, *Global Protocol for Community-Scale GHG Emissions (GPC),* Version 0.9 – 20 March 2012, C40, ICLEI Local World Bank, UNEP, UN-HABITAT, World Resources Institute

8) [1] J. Ewing-Thiel, X. Manarolla, Policy Update: ICLEI USA draft framework for measuring and reporting community GHG emissions, Carbon Management. 2 (2011) 371–375.
9) [2] J. DESHAZO, J. MATUTE, TOWARD ACCURATE AND VALID MEASUREMENT OF GREENHOUSE GAS EMISSIONS FOR LOCAL GOVERNMENTS, ().
10) [3] Z.G. Davies, P.R. Armsworth, Making an impact: The influence of policies to reduce emissions from aviation on the business travel patterns of individual corporations, Energy Policy. 38 (2010) 7634–7638.
11) [4] P. Erickson, M. Lazarus, Revisiting Community-Scale Greenhouse Gas Inventories, Environ. Sci. Technol. 46 (2012) 4693–4694.
12) [5] UBOS, Statistical Abstract: Demographic and Health Survey, Uganda Bureau of Statistics, Kampala, 2007.
13) KCCA, Updating Kampala Structure Plan and Upgrading the Kampala GIS Unit, Kampala Capital City Authority, 2012.
14) [7] C40, ICLEI, WRI, Global Protocol for Community-Scale Greenhouse gas Emissions (GPC), 2012.
15) [8] Cities and Climate Change - Initial lessons from UN-HABITAT, UN Habitat,
16) [9] UN Habitat, Cities and Climate Change: Global Report on Human Settlements, 2011, Earthscan / UN HABITAT, 2011.
17) [10] Yerushalmi. L, 2009. Contribution of on-site and off-site GHG emission of WWTP.pdf, (n.d.).
18) [11] K. Vermeiren, A. Van Rompaey, M. Loopmans, E. Serwajja, P. Mukwaya, Urban growth of Kampala, Uganda: Pattern analysis and scenario development, Landscape Planning 106 (2012) 199–206.
19) [12] IPCC - Task Force on National Greenhouse Gas Inventories, (2006).
20) [13] B.P. Chadwick, Transaction costs and the clean development mechanism, Natural Resource. Forum. 30 (2006) 256–271.
21) [14] UBOS, Uganda Update on Population and Development, (2009).
22) [15] Responding to the challenge of global change in Africa: the role of geospatial information technologies, (n.d.).
23) [16] M.R. Boswell, A.I. Greve, T.L. Seale, Greenhouse Gas Emissions Inventory, in: Local Climate. Action Plan., Island Press/Centre for Resource Economics, Washington, DC, 2012: pp. 87–114.
24) [17] S. McDonnell, S. Ferreira, F. Convery, Using Bus Rapid Transit to Mitigate Emissions of CO_2 from Transport, Transp. Rev. 28 (2008) 735–756.
25) [18] D.A. Rodríguez, C.H. Mojica, Capitalization of BRT network expansions effects into prices of non-expansion areas, Transp. Res. Part Policy Pr. 43 (2009) 560–571.
26) [19] P. Annez, R. Buckley, J. Kalarickal, African Urbanization as Flight? Some Policy Implications of Geography, Urban Forum. 21 (2010) 221–234.

27) [20] B. Fields, From Green Dots to Greenways: Planning in the Age of Climate Change in Post-Katrina New Orleans, J. Urban Des. 14 (2009) 325–344.
28) [21] M. Jenks, M. Jenks, R. Burgess, Compact cities: sustainable urban forms for developing countries, Taylor & Francis, 2000.
29) [22] Lwasa S, and C. Kinuthia-Njenga, Reappraising Urban Planning and Urban Sustainability in East Africa, (2012).