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Decentralized composting instead of landfilling of organic waste - greenhouse gas reduction from a potential CDM project in Kumasi, Ghana

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ABSTRACT

Decentralized composting instead of landfilling of organic waste - greenhouse gas reduction from a potential CDM project in Kumasi, Ghana

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Emission reduction of greenhouse gases generated from a landfill has within the framework of a Clean Development Mechanism (CDM) project been estimated concerning a potential compost project in the 1.9 million city of Kumasi, Ghana. The emission reductions mainly concern methane (CH_4) and originate from the event that the management of organic solid waste, which currently is deposited at Kumasi's only formal landfill, instead is to be composted at 124 decentralised compost stations relocated in the city. The compost stations would, according to the idea in this report, replace the 124 waste stations to which the majority of the Kumasi citizens presently leave their wastes.

Methane gas is generated in the landfill as a result of the anaerobic environment that has arisen. This environment is a consequence of the event that the decomposition of organic material initially consumes the present oxygen and is maintained by the lack of oxygen supply. Composting is on the other hand an aerobic process where methane formation hence is prevented. This is the core of the following emission reduction project, since methane is estimated to contribute to global warming 21 times the impact of carbon dioxide according to the concept of Global Warming Potential adopted by the UN Framework Convention on Climate Change (UNFCCC).

CDM projects generally mean that countries with emission reduction commitments according to the Kyoto Protocol can invest in emission reducing arrangements in countries without emission reducing commitment and thereby earn so called emission credits (CERs) while the hosting country gain sustainable technique within the framework of the CDM project. This study is based on data on waste volumes, waste fractions, climate data and CDM rules and resulted in an emission reduction by 0.1 Tg CO_2 equivalents per year during the first seven years period of the 21 years this potential CDM project eventually could proceed.

Keyword: CDM, compost, decentralized composting, greenhouse gas, emission reduction, carbon dioxide equivalents, Kumasi, Ghana.

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REFERAT

Decentraliserad kompostering istället för deponering av organiskt avfall – växthusgasreduktion från ett potentiellt CDM-projekt i Kumasi, Ghana

Andreas Boström

Utsläppsminskning av växthusgaser från deponi inom ramen för Kyotoprotokollets mekanism för ren utveckling (Clean Development Mechanism eller CDM) har i följande studie uppskattats för ett potentiellt komposteringsprojekt i 1,9 miljonerstaden Kumasi i Ghana. Minskningen av växthusgasutsläpp åsyftar främst metan (CH_4) men även delvis koldioxid (CO_2) och kommer av att organiskt avfall, som i dagsläget placeras på Kumasis enda formella deponi, istället komposteras vid någon av 124 decentraliserade komposteringsstationer utlokaliserade runtom i Kumasi. De 124 komposteringsstationerna ersätter enligt denna studie de 124 avfallsstationer till vilka huvudparten av invånarna i Kumasi i nuläget lämnar sitt avfall.

Metangasen genereras i deponin till följd utav att en anaerob miljö skapas, vilket i sin tur beror av att nedbrytningen av organiskt material initialt förbrukar det närvarande syret och miljön vidmakthålls genom att tillförseln av syre inte är tillräcklig. Att kompostera är en aerob process där metangas således förhindras att bildas. Detta är utsläppsminskningsprojektets själva kärna, eftersom metangas beräknas påverka uppvärmningen av klimatet 21 gånger effektivare än koldioxid, enligt det koncept för global uppvärmningspotential (Global Warming Potential eller GWP) som anammats av FN:s klimatkonvention (UNFCCC).

CDM-projekt innebär i allmänhet att länder med utsläppsminskningsåtaganden enligt Kyotoprotokollet kan investera i utsläppsminskande åtgärder i länder utan utsläppsminskningsåtaganden och därigenom erhålla så kallade utsläppskrediter (CERs) i utbyte mot att värdlandet mottar hållbar teknik inom ramen för CDM-projektet. Denna studie är baserad på uppgifter om avfallsmängder, avfallsfraktioner, klimatdata och CDM-reglementen och resulterade i en minskning av 0,1 Tg CO_2 ekvivalenter per år under den första sjuårsperioden av de 21 år som detta potentiella projekt kan ha möjlighet att fortskrida.

Nyckelord: CDM, kompost, decentraliserad kompostering, växthusgas, utsläppsminskning, koldioxidekvivalenter, Kumasi, Ghana.

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PREFACE

This report is a result of my master's thesis studies in order to fulfill my degree as Master of science in Environmental engineering. The report is associated with an ongoing research on waste management challenges in Kumasi, Ghana, performed by PhD Doctor and Researcher Cecilia Sundberg at the Department of Energy and Technology of Swedish University of Agricultural Sciences in Uppsala. Dr. Cecilia Sundberg has also been supervising this study and to her I would like to express my gratitude for her advice and support throughout this process.

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POPULÄRVETENSKAPLIG SAMMANFATTNING

När människan konsumerat och förskjutit, lagt på hög och förträngt, händer det att flyktförsöken gör sig påminda. Kanske växer avskrädet över alla bräddar, kanske sipprar en unken luft upp från det man försökt gömma djupt nere. Inte sällan luktar atmosfären illa där en hund ligger begraven. Dessa ord, som kanske gäller mer än en företeelse i människans liv och historia, har möjligtvis en likartad lösning; fram i ljuset! Detta kan åtminstone sägas om grundprocessen i denna text, där ruttnande avfall byts mot komposterat.

Växande befolkningar och ändrade konsumtionsvanor har lett till växande sopberg eller deponier. Dessa är, förutom att vara arenor för hälsorisker och odörer, på senare tid även erkända som källor till växthusgaser som befaras utgöra en bidragande orsak till ökande temperaturer på jordklotet. Metan är en av de växthusgaser som bildas i deponier när bakterier som bryter ner organiskt material inte har tillgång till syre. Detta sker ofta ett stycke ner under ytan på ett sopberg. Om bakterierna däremot har tillgång till syre när de bryter ner organiskt material bildas istället koldioxid och detta är den process som kallas för kompostering. Både koldioxid och metan är växthusgaser, men enligt en modell som antagits av FN:s klimatkonvention (UNFCCC) har metan 21 gånger högre potential att värma klimatet än koldioxid. Denna modell sätter alla växthusgaser i relation till koldioxid och har därför introducerat begreppet koldioxidekvivalenter (CO_2e), där alltså ett ton metangas skulle motsvara 21 ton koldioxidekvivalenter enligt resonemanget ovan. Ungefär fem procent av alla de växthusgasutsläpp som sker på jorden och har sin grund i mänsklig verksamhet kommer just från deponier. Detta gör att det finns en poäng med att reformera avfallshanteringen, som fortfarande till stor del består av att allt vi konsumerat läggs på en och samma hög, utan sortering, återvinning eller kompostering.

Sådant är läget i Kumasi, Ghanas andra största stad med en befolkning på ungefär 1,9 miljoner människor. I ett försök att utreda hur mycket man i denna stad skulle kunna minska på metanutsläppen från den deponi där det mesta av stadens avfall hamnar har denna studie tillkommit. Uppdraget är att göra det med hjälp av en mekanism som upprättats av Kyotoprotokollet och kallas mekanismen för ren utveckling (Clean Development Mechanism eller CDM). Genom Kyotoprotokollet ålades 38 av världens industrialiserade länder att minska sina utsläpp med 5,2% av vad varje enskilt land i genomsnitt släppte ut år 1990. Detta mål skulle uppnås under perioden 2008 – 2012, och ett av flera sätt att gå till väga på var genom denna nämnda mekanism. Mekanismen för ren utveckling låter ett land som har krav på sig att minska sina växthusgasutsläpp investera i utsläppsminskande projekt i länder som inte har några krav på sig att minska sina växthusgasutsläpp. De senare är huvudsakligen utvecklingsländer som genom detta projekt får hållbar teknisk utveckling och i gengälld får det investerande landet tillräkna sig utsläppsminskningen som projektet lett till genom så kallade utsläppskrediter. Krediterna kan sedan användas till att tillgodose en del av de egna utsläppsminskningsåtaganden eller säljas vidare till andra.

Majoriteten av Kumasis invånare lämnar i dagsläget sitt avfall vid någon av de 124 olika sopcontainrar som är utlokaliserade runtom i staden. Dessa containrar töms av kontrakterade privata företag som levererar avfallet till den deponi som ligger inom staden i närheten av Dompoase. När nu det organiska avfallet, enligt tanken i denna studie, ska komposteras istället för att deponeras så är planen att de 124 sopcontainrarna med angränsande område omvandlas till decentraliserade komposteringsanläggningar. Mängden avfall som dagligen levereras till Dompoase-deponin är 900 ton och består till hälften av organiskt komposterbart material. Detta skulle leda till att ungefär 3,6 ton organiskt material behöver tas omhand varje dag vid varje kompoststation medan samma mängd okomposterbart material skulle behöva levereras till deponin. Någon sopsortering i hushållen sker inte i nuläget och försök som gjorts visar på en villighet till sopsortering men ger även en aning om att en avsevärd ansträngning återstår för att få detta till stånd. Utsortering av det organiska materialet kommer därför ske av personal vid komposteringsstationerna, vilket är ett krävande arbete både tidsmässigt och arbetsmiljömässigt. Komposteringsprocessen kommer att underlättas genom enkel och lättskött teknik där luftningen, för att hålla processen syrerik, sker genom så kallad windrow-teknik. Det komposterbara materialet läggs då över en triangulär träbock uppbyggd med relativt glesa brädor, vilket skapar en lufttillförsel underifrån och som kommer kombineras med att personal manuellt blandar om komposteringsmaterialet.

Den utsläppsminskning av växthusgaser som genom detta projekt skulle vara möjlig beräknas genom att enligt CDM-metodiken bestämma den nivå av metangasutsläpp som skulle ske i frånvaro av ett CDM-projekt. Detta blir sedan den minskning av metangasutsläpp som beräknas ske minus de utsläpp som kan tillkomma till följd av projektet och eventuella läckage som sker utanför det geografiska område som avgränsats för projektets processer men som ändå kan tillräknas projektet.

Den utsläppsminskning av växthusgaser som beräknats kunna ske genom CDM-projektet är 0,1 Tg CO_2e per år, vilket kan sättas i relation till de totala globala utsläppen från avfallshantering och som är i storleksordningen 1500 Tg CO_2e.

”Allt kött är hö,

och blomstren dö,

och tiden allt fördriver;

blott Herrens ord förbliver.”

- Carl David af Wirsén (1889)

ABBREVIATIONS

AAU – Assigned Amount Unit

AMS – Approved Small-scale Methodology

BE – Baseline Emission

CDM – Clean Development Mechanism

CER – Certified Emission Reduction

CERs – Certified Emission Reduction credits

ER – Emission Reduction

ERU – Emission Reduction Unit

EU – European Union

FOD – First Order of Decay

GHG – Green House Gas

GWP – Global Warming Potential

IPCC – Intergovernmental Panel on Climate Change

IWMI – International Water Management Institute

JI – Joint Implementation

KMA – Kumasi Metropolitan Assembly

LE – Leakage Emission

PE – Project Emission

SWDS – Solid Waste Disposal Site

UNFCCC – United Nations Framework Convention on Climate Change

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1. INTRODUCTION

Landfilling is and has for a long time been the most common waste management worldwide. Moreover, landfills have been disreputable due to public health issues (Lou & Nair, 2008) and offensive smell. Lately a growing concern for climate change suspiciously caused by global warming has even more shaded the picture of landfills, now as a source for greenhouse gas (GHG) emissions, where methane from anaerobic decomposition is of certain distress due to its relatively high abundance and global warming potential. The contribution to GHG emissions from waste management is computed to be approximately 5% of the global greenhouse budget (IPCC, 2006)

In 1997 38 countries ratified the UN initiated Kyoto Protocol and thereby agreed on reducing their GHG emissions to a certain level. One of a few agreed ways to go about this challenge was through the Clean Development Mechanism (CDM). This mechanism allows countries with emission commitments to participate in projects that take place in countries without emission reduction demand. The projects aim to reduce emissions in the host country, which in return gets sustainable technology from the investing country. Depending on the amount of emission reduction achieved by the project, the corresponding amount of certified emission reduction (CER) credits accrues the investors. They can either use the credits to meet their own emission target or sell them on the market.

Ghana is one of the countries that so far have no emission reduction commitments to accomplish when it comes to the Kyoto Protocol and is therefore fit for being a host country for CDM projects. Kumasi is the second biggest city in Ghana and as generally depicted above, this city's waste management is mainly a matter of a growing area of landfills, official or informal (Drechsel et al, 2004). An opportunity to change waste treatment from anaerobic to aerobic with the help of foreign CDM-capital is thus possibly available for Kumasi, which may decrease both landfill expansion and greenhouse gas emissions. One aim of this report is to examine to which extent GHG emission may be reduced within the framework of a CDM project.

1.1. BACKGROUND

Figure 1 Map highlighting Kumasi's location in Ghana, Africa (Embassyworld, 1998) (Worldmapfinder, 2002).

1.1.1. Kumasi

The second largest city of Ghana is Kumasi, populated by approximately 1.9[1] million people. In daytime 2004 Kumasi could even be hosting up to the double of its population (Drechsel et al, 2004) as a result of its market trade places being the biggest in central Ghana. Situated in the tropical forest zone with a semi-humid climate, one of its main industries is forestry, with more than 60 sawmills located in the city. The rain pattern in Kumasi is bimodal with March – July and September – October being the rainy period and the remaining months being dry. This influences the time for the crop harvest, which in turn means an increased waste generation during this period. Two thirds of the households have some sort of backyard farming and a much higher fraction has in a minimum one plantain or a few chickens. The peri-urban area of Kumasi is spread about 40 km from the centre of the city. A significant part of this region is characterized

[1] Based on the latest population census made in 2000 resulting in 1,17 million people and a population growth of 5,4 % per year (Erni et al, 2007)

by large poultry farms providing farmers with low-cost fertilizer. The city is run through by a couple of river branches that far south of Kumasi joins together in the Oda River that among other things serves as drinking water source for communities downstream as well as illegal dumpsite.

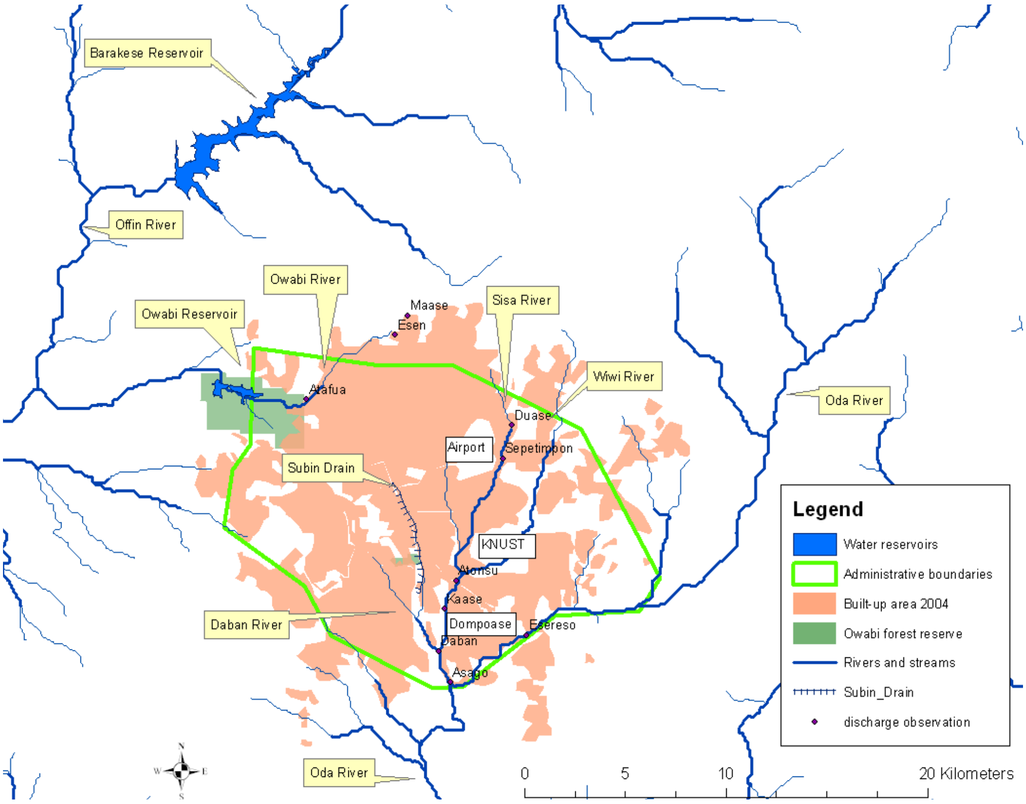

Figure 2 Kumasi (Enri, 2007).

1.1.2. Waste Management in Kumasi

The waste management in Kumasi 2004 concerning households, market places, industry, night soil[2] and livestock manure was described in a report by Drechsel (2004). It stated that

- **households** generate 260 000 t waste/year where 56% was collected and deposited on a landfill south of the city near Dompoase, which is the only active landfill in Kumasi. 20% was estimated to become animal feed while 24% was dumped in water bodies or informal dumps.
- Kumasi's four biggest **market** places were estimated to generate 90 000 t waste/year where 88-90% was collected to a landfill and the rest estimated to become animal feed.

[2] Night soil is a name for human excreta.

- When it comes to **industries** in Kumasi, sawmills generate 230 000 – 290 000 t/year. However only 27% are dumped on a landfill or burnt. 43 000 t/year is dumped in the river. Five slaughterhouses exist in Kumasi which together have the capacity to generate waste in the magnitude of 2 700 t /year.

- Two sites for **night soil** exist which in 2004 had not been desludged yet. It was though estimated that they could generate 2100 t sludge/year. 40% of livestock manure from poultry farms is directly used as fertilizer. Remaining 60% would imply 2 200 t/year which could be utilized to improve the amount of nutrients in the compost.

Of all waste generated in Kumasi, which is estimated to be 0.6 kg per capita and day (Ketibuah et al, 2005), 900 tonnes are estimated to reach the landfill near Dompoase (Adjei-Boateng, pers. comm).

Most of the citizens in Kumasi deliver their solid waste into one of the 124 solid waste stations spread around the city. These stations consist of a container that is emptied by one of the private companies contracted for this by the Waste Management Department (Wikner, 2009). In some districts house-to-house collection is introduced (Drechsel et al, 2004). No source separation of household waste exists. However, several pilot attempts have been made as late as in 2008 (Asase, 2008)

1.2. OBJECTIVE

The purpose of this report is to calculate to which extent a change of the Kumasi waste management, from depositing to composting organic waste, could reduce greenhouse gas emissions using the Clean Development Mechanism (CDM) as method. Furthermore, the report aims to relate the calculated emission reduction to the amount of certified emission reduction (CER) credits that thereby could be generated.

1.3. LIMITATIONS

This study will not immerse into economical aspects of the CDM project like the concept of additionality (see chapter 3.5.). However, it will estimate the market value of the Certified Emission Reduction (CER) Credits (see chapter 3.3.) estimated through this study.

2. METHOD

Guided by requirements on how to set up a CDM-project outlined in documents from United Nations Framework Convention on Climate Change (UNFCCC, 2009) information was obtained concerning; information on waste management in Kumasi in terms of quantities of waste generation ending up at the landfill, waste qualities in terms of fractions in order to estimate the carbon content, waste transports, waste collection, demography data, climate data and compost plant setup requirements. The source of information is mainly through reports from studies on site in Kumasi along with more general reports on waste management. Personal contacts in shape of telephone and e-mail communication were also a significant source of information. This study was carried out in Uppsala, Sweden, without any personal on site study in Kumasi from the author's perspective, but supervised and in contribution from people with on site experience.

Obtained information was applied in a methodology for the specific potential project described below and processed in Windows Excel software in order to calculate the included equations resulting in a potential greenhouse gas emission reduction in Kumasi.

3. LITERATURE STUDY

3.1. KYOTO PROTOCOL

In 1997 the parties that earlier in 1992 signed the UN Framework Convention on Climate Change (UNFCCC) were assembled in Kyoto for the recurring Conference of the Parties. This conference resulted in an agreement called the Kyoto Protocol that covers a set of binding emission commitments for 38 industrialized countries. These countries are commonly called Annex I-countries though all of the Annex I countries have not yet ratified the protocol, among others the United States of America. Three of the six[3] greenhouse gases for which the protocol dictate emission constraints are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In order to compare these gases to each other they are converted into CO_2 equivalents (CO_2e), which is an approach adopted by the Intergovernmental Panel on Climate Change, using the gases Global Warming Potential (GWP) under period of 100-years (Harvey, 1993). The GWP is the time-integrated contribution to the balance of incoming solar radiation and planetary radiation from the release of one kilogram of gas compared to that from one kilogram of carbon dioxide (Holmgren et al, 2007). The commitment that the Annex I countries agreed on for the first commitment period (2008 – 2012) is a mean reduction of the issued greenhouse gases by 5.2% of the 1990 emission level for each of these countries. During this first commitment period, non-Annex I countries, which primarily consist of developing countries, have no limitations of their GHG emissions, when it comes to the Kyoto Protocol. This is the case in order not to hinder their opportunity to economical and industrial development and is justified by the fact that the industrialized world is responsible for the historical increase of greenhouse gases in the atmosphere and still is the part that contributes with most GHG emissions (Michaelowa et al, 2007). Countries with no emission reduction commitment under the Kyoto protocol still need to accept the protocol in order to be able to participate as a host country for mechanisms like CDM-projects (Point Carbon, 2009). Non-Annex I countries that have accepted the Kyoto Protocol are obliged to report on their GHG emissions (Michaelowa et al, 2007).

[3] The other three are Hydro-flour carbons (HFCs), Perflourocarbons (PFCs) and Sulphur hexafluoride (SF_6) which are industry related gases and therefore not relevant for this report.

3.2. CDM CONCEPT

In order for a country to reach their emission reduction target the Kyoto Protocol decided on a few ways to go about this challenge. One of these is called Clean Development Mechanism (CDM). The underlying principle is the fact that the greenhouse effect is global. Hence, no matter where greenhouse gases are added to the atmosphere they are anyway spread all around the globe and alter the composition of the atmosphere everywhere. Consequently a reduction of greenhouse gases in one place of the earth is equally meaningful as if it happened elsewhere on the planet. CDM is a project-based mechanism that uses this "global principle" by allowing countries[4] with emission commitments to invest in emission reducing projects in countries without emission commitments[5]. Thereby the investors get certified emission reduction (CER) credits that can be used either to reach a part of their emission target or be sold in the market to other countries or companies with emission commitments. On the other hand, the host country gets sustainable technical development. The credits can be accumulated during the lifetime of a project which is defined as either 10 years or 7x3 years with an update of a baseline scenario after every seven year period. The reason for a country with emission commitments to place their own struggle with emission reduction in a developing country instead of simply reducing their own emissions is a matter of simplicity and efficiency. A large emission reduction can namely by relatively simple means, with their own proven technology, be achieved in a developing country, which would be cost efficient and simple in the sense that the adequate technology is already available. However, a country with emission commitments cannot use CERs alone to reach their goal. The CERs may only partly account for a country's emission reduction commitment.

3.3. CERTIFIED EMISSION REDUCTION (CER) CREDITS

That a country has a GHG emission commitment due to the Kyoto Protocol becomes of course along the line a matter for its GHG emitting companies. The matter has a number of possible solutions or combinations of solutions. A company that applies to its national authorities to emit GHGs can be permitted to a level of emission allowances or so called "assigned amounts" divided into units called Assigned Amount Units (AAUs) (UNFCCC II, 2009). Every unit corresponds to the emission of one metric tonne of carbon dioxide equivalent (CO_2e) (11/CMP.1, 2005). If a company has emission units to spare, these AAUs can be traded with among companies. Another way to fulfil the emission commitment is through a mechanism similar to the Clean Development Mechanism called Joint Implementation (JI). This is like CDM a project based mechanism but it engages only Annex I countries and generates Emission Reduction Units (ERUs). Finally, Certified Emission Reduction (CER) credits can be acquired and traded through

[4] Not only countries can invest in CDM-projects but companies and all that can be named juridical person (Möllersten, 2009, pers. comm).

[5] A country can within the frame of the Kyoto Protocol be without emission commitment due to low economic development and therefore no historical responsibility for anthropogenic GHG emission.

a CDM-project. In the European Union every nation forms a national allocation plan over their emission allowances which have to be approved by the EU commission (Naturvårdsverket, 2007).

The UNFCCC administrates an International Transaction Log which verifies that transactions of inter alia AAUs, ERUs and CERs follow rules agreed on in the Kyoto Protocol (UNFCCC III, 2009). The CER market has developed into two pricing categories, namely primary and secondary CERs. The primary CERs are those that the project owner sells to an investor. This often takes place before any CERs are registered by the International Transaction Log, which results in a risk for the investor why the price is lower compared to secondary CERs (Hansén, 2007). The price for primary CERs are therefore custom-tailored for every project (Cantor CO2e, 2009). Secondary CERs is the term for CERs that are not sold by the project owner but by a bank or a factor just like AAUs. In this case prices can be estimated by looking in to the current market prices.

3.4. CDM METHODOLOGY

When a CDM project is being formed a methodology describing the procedure and measures for the realization of the project has to be approved by the Executive Board, which is the institution that oversees all CDM activities. Once a methodology is approved it can be reused in similar projects. Specifically regarding this report a methodology titled "*Avoidance of methane emissions through controlled biological treatment of biomass*" (EB48, 2009), also named AMS[6] III F, was selected as methodology for the potential CDM project applied in Kumasi in order to calculate emission reduction.

AMS III F

The AMS III F methodology "comprises measures to avoid the emissions of methane to the atmosphere from biomass or other organic matter that would have otherwise been left to decay anaerobically in a solid waste disposal site" (CDM-EB, 2009). AMS III F is also a so called small-scale project methodology implying a simplified procedure valid for projects reducing emissions to a lesser portion than 60 000 tCO_2e/year. It is valid for treatment of the organic fraction of municipal solid waste apart from manure.

3.5. METHODOLOGY REQUIREMENTS

For a project to be approved by the Executive Board there are some requirements attached to the methodology that have to be fulfilled. The parties involved in the CDM project establishes a so called Project Design Document that describes the project and gives all required data needed for a validation. A CDM project must be approved in the light of the additionality concept. This is an economical aspect that determines if the project would have happened even without the contribution of a CDM project (Michaelowa et al, 2004). Barriers that the hosting country, in absence of a CDM project, would not be able to surmount have to be proved in the Project

[6] approved small-scale methodology (AMS)

Design Document. These barriers comprise financial, technical, project prevailing and other aspects but will not be further investigated in this study

A specific requirement of the AMS III F methodology is that it has to be proven that the environment in the landfill is anaerobic. Furthermore, the project participants need to present a technique for prevention of methane formation. It is also required that the project reduces less than 60 000 tCO_2e/year, since the AMS III F is a so called Small-Scale project which benefits from some simplified regulations in comparison to large-scale projects.

3.6. PROJECT BOUNDARY

Every project takes place within a specified geographic area defined by a project boundary. This area includes “all anthropogenic emissions by sources of greenhouse gases under the control of the project participants that are significant and reasonably attributable to the CDM project" as formulated by the Conference of the Parties (3/CMP.1, 2005). Regarding this report the project boundary encompasses a number of decentralised compost plants in Kumasi. The landfill in Dompoase and the sites where the compost product will be delivered is also included in the project boundary as is the route between these different compartments.

3.7. TRANSPORTS

When it comes to transports the AMS III F only takes into account changes in transports that have occurred since the project started. By this follows that the transports need only be accounted for in the direction away from the compost plants since the transports to the plants are assumed to be the same as the transports to the waste stations. Transports away from the compost plants involve firstly the solid waste that still has to be landfilled, which is estimated to be 50% of the total solid waste (Drechsel et al, 2004). Secondly, the readily available compost product is also transported away from the plant a distance assumed to be on average 25 km.

3.8. COMPOSTING

The fate of organic matter, once it is dead, is to decompose. In an aerobic environment the aerobic type of micro-organisms that run this decomposing process do, as a result of their metabolism, consume oxygen and produce simpler hydrocarbons, carbon dioxide, water and heat.

Organic Solid Waste + O_2 → HC[7] + CO_2 + H_2O + heat

This is the core of the compost process which renders desirable outcomes like stabilisation[8], volume reduction and thermal inactivation of pathogens (Sundberg, 2005). Composting is a relatively fast process of 4-6 weeks until stabilised (Williams, 2005). The prosperity of a compost process is ultimately the prosperity of its micro-organisms. For instance is the oxygen within a

[7] Hydro Carbon

[8] This means to produce material that does not putrefy, self-heat, consume oxygen, produce offensive smell and does not attract vermin.

pore consumed by the micro-organisms within minutes which illustrates partly the crucial need of oxygen to maintain an aerobic process and partly the regularity that methane is formed even in a compost process. Is the environment instead anaerobic, micro-organisms generate partly methane, CH_4, as an outcome of their metabolism.

The anaerobic environment in a waste pile has three different stages. The first begins after the oxygen is depleted. This and the following stages result in the generation of hydrogen, carbon dioxide and methane (Williams, 2005).

Organic Solid Waste → $H_2 + CO_2 + CH_4 + H_2O$ + Organic Acids + Ammoniacal acids

4. CALCULATIONS

4.1. AMS III F METHODOLOGY

The AMS III F methodology results in the calculation of the emission reduction (ER) obtained by the CDM project. Its governing equation is:

$$ER_y = BE_y – (PE_y + LE_y), \qquad (1)$$

where:

ER_y = emission reduction in year y (tCO_2e)
BE_y = baseline emission in year y (tCO_2e)
PE_y = project emission in year y (tCO_2e)
LE_y = leakage emission in year y (tCO_2e).

The ways to assess the emission reductions generated by the CDM project is hence through calculating a baseline and subtract the project emissions and adjust for leakage. The elements in Equation 1 will one by one be considered below.

The baseline is the amount of anthropogenic GHG emissions that would have been emitted without the CDM project taking place (Michaelowa, et al., 2007), whereas project emission is the GHG emissions occurring after a CDM project is introduced. Leakage is “net change of anthropogenic emissions by sources of greenhouse gases which occurs outside the project boundary, and which is measurable and attributable to the CDM project” (3/CMP.1, 2005).

4.2. BE_Y – DESCRIPTION AND ESTIMATION OF THE BASELINE

The baseline emission (BE) situation is when organic matter continuously is deposited on the solid waste disposal site near Dompoase. In case of no collection of landfill gas (methane) from the landfill, as the case is in Dompoase (Wikner, 2009), BE_y is named $BE_{CH4,SWDS,y}$ indicating the methane emissions avoided from dumping waste at a solid waste disposal site (SWDS). In order to calculate $BE_{CH4,SWDS,y}$ a tool has been approved by the Executive Board that is applicable for more methodologies than only the AMS III F methodology and is called *"Tool to determine methane emissions avoided from dumping waste at a solid waste disposal site"*(EB41, 2008). This is a First Order of Decay (FOD) model taking into account aspects like decay rate of different waste fractions and the amount of waste deposited at the landfill every year, possible methane capturing, oxidation cover of landfill, fraction of methane in landfill gas, fraction of degradable carbon in waste fractions, aspects of methane generation due to level of landfill management. The model will be more elaborately described in chapter 6.2.

4.3. PE_Y – DESCRIPTION AND ESTIMATION OF THE PROJECT EMISSIONS

Project emissions are those emissions that occur due to the CDM-project. According to the AMS III F, project emissions are divided into following sections:

$PE_y = PE_{y,transp} + PE_{y,power} + PE_{y,comp} + PE_{y,runoff}$

where

$PE_{y,transp}$ - Emissions from incremental transportation in the year y (tCO_2e);
$PE_{y,power}$ - Emission from electricity or fossil fuel consumption in the year y(tCO_2e);
$PE_{y,comp}$ - Methane emissions during composting process in the year y (tCO_2e);
$PE_{y,runoff}$ - Methane emissions from runoff water in the year y (tCO_2e).

Verified data on this shall continuously be submitted to the Executive Board. Thus, the calculation is an estimation that in case of an actual CDM-project should be based on monitored data.

4.4. LE_Y – DESCRIPTION AND ESTIMATION OF THE LEAKAGE

Leakage is anthropogenic GHG emissions that happen due to the CDM project but occurs outside of the project boundary but yet is attributable to the CDM project (Michaelowa et al, 2007). However, no such activities are assumed why leakage emissions (LE_y) are ignored in further calculations.

5. COMPOST PLANT SET-UP

The idea of utilizing decentralized compost plants instead of one large plant is motivated by aspects as:

- Technology – simple technology can be used which vouches for a more sustainable compost plant since maintenance of technical machinery does not require much money or a high level of specialized skills.
- Transports – transport distances are reduced leading to reduced fuel dependency which benefits both economy and the environment, including an additional decrease of greenhouse gas emissions.

- Labour – decentralized compost stations are labour-intensive. This results in more people employed and can therefore be seen as an opportunity for poor and socially deprived people (Rothenberger & Enayetullah, 2006).

The use of decentralized compost plants also stands in line with recommendations from a large investigation made in Kumasi by International Water Management Institute (IWMI) (Drechsel et al, 2004).

As mentioned earlier, the citizens deliver their household waste to one of 124 waste stations in the city. These stations are in shape of a container that is emptied by waste collecting companies on regular basis (Wikner, 2009). The plan, as sketched out in this report, is that the compost plants will replace these waste stations.

The daily total waste supply to the Dompoase landfill is estimated to be 900 tonnes/day (Adjei-Boateng, pers. comm). The IWMI report (Drechsel et al, 2004) estimated that 50% of the waste is organic matter. Hence 450 tonnes organic waste is supposed to be taken care of every day at the decentralized compost stations. Having in mind the number of 124 potential compost stations this results in an approximate amount of 3.6 tonnes organic waste to be processed every day at each station. The amount can be compared to a capacity value for decentralized composts of up to five tonnes presented in a handbook on decentralized composting (Rothenberger & Enayetullah, 2006). This handbook also estimates that a compost plant that processes three tonnes of organic waste per day requires an area of about 1000 m^3.

In the setup of these compost stations no source separation of the household waste is assumed since this is not yet in practise in Kumasi. A pilot project on waste separation at source in Kumasi was carried out in 2008 resulting in some recommendations for implementation (Asase, 2008). Lack of source separation are likely to aggravate the process since the separation is both labour-intensive and tedious (Rothenberger & Enayetullah, 2006).

A sketch of the compost plants as they could appear in Kumasi is in the following part briefly outlined. The waste enters the compost plant at the sorting area and is along the process moved through the compost area, maturing area, screening and bagging area and ends up at a temporary storage before loaded for transport. This process all takes place on a concrete floor with a 1% slope to enable collecting of leaking fluids from the composts. The leaching wastewater can in addition to water from cleaning the facility and an on-site fresh water source be used to maintain a productive moisture content in the compost. The process is preferably occurring under roof or under a composting fleece to protect from excessive rain and sun. Remaining part of the compost site is covered by storage buildings, vehicle parking and facilities for the workers such as an area for breaks, toilets and washing facilities. (Rothenberger, et al., 2006)

The aerobic decomposition of the organic waste will be realised through windrow composting. This is a low-cost and a low-technique solution where the waste is aerated partly through a triangular aerator (Figure 3) partly through manual turning of the waste by the workers.

Figure 3 Waste piled onto and around triangular aerators as it can look in Bangladesh (Rothenberger & Enayetullah, 2006).

6. CDM RESULTS

6.1. JUSTIFICATION OF CHOICE OF CDM METHODOLOGY

In order to be able to utilize the AMS III F methodology the ex ante condition in the landfill must be verified as anaerobic. The depth of the landfill ranges from 15 to 35 meters (Sundberg, 2009, pers. comm) and the waste composition is about 50 percent organic matter (Drechsel et al, 2004), which leads to a rather high fraction of water. These two conditions support the assumption of an anaerobic environment in the landfill.

The AMS III F also requires a prevention of methane formation (EB48, 2009). This will be ensured through a composting treatment of the organic matter using windrow technique in order to provide with oxygen.

Finally, this project qualifies as a small-scale project since it is assumed that it reduces less than 60 000 tCO_2e/year of GHG emissions (EB48, 2009). This assumption will however be confirmed in chapter 6.5 below.

6.2. BASELINE EMISSIONS, BE

The baseline emissions are calculated according to following equations.

$$BE_{CH4,SWDS,y} = \varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot \sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j (y-x)} \cdot \left(1-e^{-k_j}\right) \quad (2)$$

Where:

$$W_{j,x} = W_x \cdot \frac{\sum_{n=1}^{z} p_{n,j,x}}{z} \quad (3)$$

Table 1 beneath explains the parameters of Equation 2 as well as the values used and their sources.

Table 1 Values and explanations of the parameters of Equation 2.

Parameter	Description/(unit)	Value	Source of data[9]/Comment
φ	Model correction factor to account for model uncertainties (-)	0.9	
f	Fraction of methane captured at the Solid Waste Disposal Site (SWDS) and flared, combusted or used in another manner (-)	0	No such activity exist in Dompoase, Kumasi
GWP_{CH4}	Global Warming Potential (GWP) of methane, valid for the relevant commitment period (tCO2e/tCH4)	21	Kyoto Protocol decided on this value for the first commitment period (2008 – 2012)
OX	Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste) (-)	0	This value is valid for landfills without any covering material
F	Fraction of methane in the SWDS gas (volume fraction) (-)	0.5	IPCC 2006 Guidelines for National Greenhouse Gas Inventories.
DOC_f	Fraction of degradable organic carbon (DOC) that can decompose (-)	0.5	IPCC 2006 Guidelines for National Greenhouse Gas Inventories. The factor describes that there is carbon in the landfill that does not degrade or degrades slowly
MCF	Methane correction factor (-)	0.8	Value valid for unmanaged solid waste disposal sites (SWDS) with greater depth than 5 meters. The MCF

[9] The sources in this column are the tool for the Baseline Emission calculation (EB41, 2008)

			accounts for the fact that unmanaged SWDS produce less methane from a given amount of waste than managed SWDS, because a larger fraction of waste decomposes aerobically in the top layers of unmanaged SWDS.
$W_{j,x}$	Amount of organic waste type j presently disposed and potentially prevented from disposal in the SWDS in the year x (tons)	Appendix A1	See calculations in Appendix A1
DOC_j	Fraction of degradable organic carbon (by weight) in the waste type j (-)	DOC_j (%) / Waste type *j* (%wet weight): 43 – Wood and wood products 40 – Pulp, paper and cardboard 15 – Food, food waste 24 – Textiles 20 – Garden, yard and park waste 0 – Glass, plastic, metal, other inert material	
k_j	Decay rate for the waste type j (-) (See Appendix A 2 for determination of decay rate)	k_j / Waste type *j*: 0.035 – Wood and wood products 0.07 – Pulp, paper and cardboard 0.40 – Food, food waste 0.07 – Textiles 0.17 – Garden, yard and park waste - – Glass, plastic, metal, other inert material	
j	Waste type category (index)	See DOC_j	
x	Year during the crediting period: x runs from the first year of the first crediting period (x = 1) to the year y for which avoided emissions are calculated (x = y)	[1,7]	The first 7 years in the 3x7-year choice of crediting period
y	Year for which methane emissions are calculated	7	
$W_{j,x}$	Amount of organic waste type j prevented from disposal in the SWDS in the year x (tons)	Appendix A1	
W_x	Total amount of organic waste	Appendix A1	

	prevented from disposal in year x (tons)		
$p_{n,j,x}$	Weight fraction of the waste type j in the sample n collected during the year x	Appendix A1	
z	Number of samples collected during the year x (-)	1	No samples are collected but data is based on information of daily waste generation and waste fractions from KMA (Adjei-Boateng, pers. comm)

In order to calculate Equation 3, waste fractions and the organic waste supply to the Dompoase landfill is needed. The Waste Management Department of Kumasi Metropolitan Assembly (KMA) estimates the daily waste supply to the Dompoase landfill to 900 tonnes and the waste fractions according to Table 2 below (Adjei-Boateng, pers. comm).

Table 2 Solid Waste Fractions of Kumasi obtained from Waste Management Department of KMA (Adjei-Boateng, pers. comm)

Solid Waste Category	Fraction
Greens/vegetable/fruits	0.44
Plastics	0.035
Fabrics/textiles	0.032
Paper/cardboard	0.031
Glass	0.006
Metal	0.006
Rubber	0.003
Miscellaneous	0.446

The organic fraction in Table 2 involving Greens/vegetable/fruits, Fabrics/textiles and Paper/cardboards reaches together 50 % of the waste fractions in Kumasi which also is the fraction IWMI indicates in its waste management report referred to previously (Drechsel et al, 2004). This can be compared to a CDM project in the Philippines with 55 % of organic waste (Nepomuceno & De Jonge, 2008). (The comparison with this Philippine project will continue throughout this report.)

The solid waste categories in the CDM-formulary (see Table 3) are however not the same as those originating from KMA and are in some parts not easily translated. In calculating Equation 3, only the organic matter is of concern why the Miscellaneous fraction, assumed to be inorganic, is not further investigated since the organic fraction already is covered in the other categories. The CDM waste categories separate the organic waste into more specific fractions than those from the KMA which imply that the KMA data carries no information of how to sort the concerned waste into the CDM categories. Each of the CDM categories contributes differently to the amount of degradable organic carbon (DOC_j) that the waste holds and therefore can be emitting. For instance, 'Wood and wood products' are assumed to contain more than the double amount of degradable organic carbon than 'Garden, yard and park waste' (see DOC_j in Table 1). This difficulty will be dealt with by investigating the outcome of a couple different scenarios. The scope of this paper to estimate a potential emission reduction will therefore result in a range instead of a discrete number.

Three categories are concerned in this question namely: Wood and wood products (Wood); Food, food waste, beverages and tobacco (Food); Garden, yard and park waste (Garden). The Food-fraction is presumed to dominate over the other two fractions since both the Wood- and Garden-fractions are likely to be reused as fuel at a much higher grade than the Food-fraction. Therefore two scenarios, where the Food-fraction dominates over the other two fractions differently, are presented. The three categories will share 44% of the waste according to Greens/vegetable/fruits in Table 2, as Figure 4 depicts and Table 3 describes.

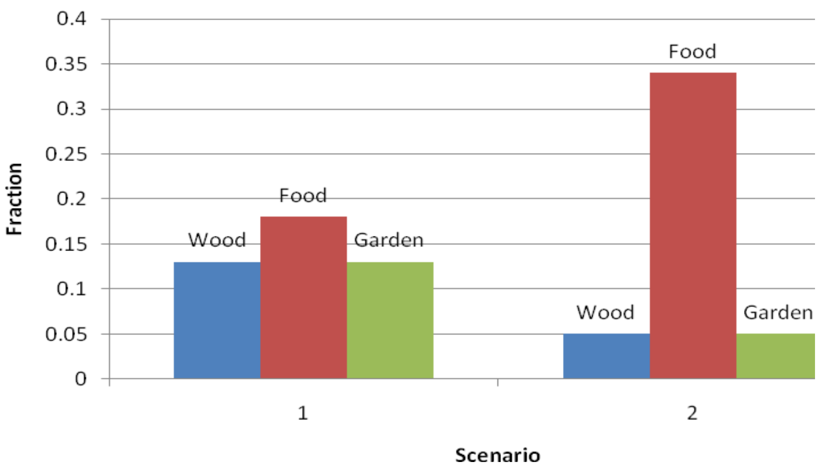

Figure 4 Two scenarios of three different organic waste categories in total waste of Kumasi.

Table 3 Solid Waste Fractions of Scenario 1 and 2 with CDM classification.

Solid Waste Category	Waste Fraction Scenario 1	Waste Fraction Scenario 2
Wood and wood products	0.13	0.05
Pulp, paper and cardboard	0.031	0.031
Food, food waste, beverages and tobacco	0.18	0.34
Textiles	0.032	0.032
Garden, yard and park waste	0.13	0.05
Glass, plastics, metal, other inert waste	0.497	0.497

Based on the values in Table 1 and Table 3 the baseline emission, BE, for the first seven years of the potential CDM-project was calculated, taking in account that population increases with 5,4%

per year and hence the waste generation. It is also assumed that the solid waste left at informal deposits will decrease and thereby increase the waste generation by 1% every year. The details in these calculations are presented in Appendix 1 where Scenario 1 is especially focused. The entire baseline emission calculation resulted in;

BE_7 = 133 000 – 144 000 tCO_2,

where 133 000 tCO_2 refers to Scenario 1 with less food in the waste fraction than in scenario 2, which baseline hence is calculated to 144 000 tCO_2. Thus, if continued disposal of organic waste in the solid waste disposal site near Dompoase took place, 133 000 – 144 000 tCO_2e would be emitted over a period of seven years.

6.3. PROJECT EMISSIONS, PE

Due to the low-technology compost plant setup described in chapter 5 the only power consumption would be from storage facilities and workers facilities. This power consumption is assumed to be small and therefore this part is ignored. This assumption is supported by following example:

The use of a refrigerator can serve as an example to support this assumption. An old refrigerator consumes about 500 kWh/year (Vattenfall, 2009). Using the following expression to calculate the contribution to the project emissions of a refrigerator running seven years,

$PE_{y,power}= EF_{CO2}$ (electricity) $\cdot$ power used for electricity, result in:

$PE_{7,power}$=0.42 $kgCO_2$/kWh[10] $\cdot$ 500 kWh/year $\cdot$ 7 years= 1,47 tCO_2.

If every one of the 124 stations would have a refrigerator the project emission would reach approximately 200 tCO_2 after seven years due to the refrigerators. Hence, the impact on GHG emission from items like fridges, electric light and similar items are far away from the avoided emissions from the landfill which is in the magnitude of 100 000 tCO_2/7 years.

Also $PE_{y,comp}$ and $PE_{y,runoff}$ are ignored since these assumes that an anaerobic environment would occur which is supposed not to happen. Thus, ending up only with emissions from incremental transports this part can be divided in two sections as revealed in the formula below (EB48, 2009):

$$PE_{y,transp} = (Q_y/CT_y) \cdot DAF_w \cdot EF_{CO2} + (Q_{y,comp}/CT_{y,comp}) \cdot DAF_{comp} \cdot EF_{CO2} \qquad (4)$$

Where

Q_y – quantity of waste composted in year y (tonnes)
CT_y – average truck capacity for waste transportation (tonnes/truck)

[10] (Nepomuceno & De Jonge, 2008)

DAF_w – average incremental distance for waste transportation (km/truck)
EF_{CO2} – CO_2 emission factor from fuel use due to transportation (tonnes/truck)
$Q_{y,comp}$ – quantity of compost produced in year y (tonnes)
$CT_{y,comp}$ – average truck capacity for compost transportation (tonnes/truck)
DAF_{comp} – average distance for compost transportation (km/truck)

The first term in Equation 4 describes the incremental transportations that concerns the waste transports. As mentioned before, IWMI estimate that 50% of the waste is organic. This implies that the transports from the compost plants with inorganic waste destined for the Dompoase landfill could be cut by approximately the half as well. This would decrease fuel consumption and thus the CO_2 emission derived from this part of the waste transports. However, data for this is difficult to obtain, partly since several companies are sharing the responsibility for waste collection in Kumasi, partly since data is in general hard to acquire in this area. For simplification this assumed reduction of emission due to less waste transportation is neglected which in other words sets the first term in Equation 4 to zero.

Left is then the second term in Equation 4; the part dealing with incremental transports due to handling of the compost product. Here an arbitrary distance of 25 km from the compost plants is considered.

Table 4 Calculations of project emissions, PE.

Entities	Values	Comments
$Q_{7,comp}$	630 tonnes	= (organic waste generation on seven years: 450 · 7 tonnes) · (weight reduction due to water loss: 0,2[11])
$CT_{y,comp}$	3.4 - 13.6 tonnes/truck	= (compost density: 1.7[12] tonnes/m^3) · (truck capacity: 2-8[13] m^3/truck)
EF_{CO2}	0,24[14] kg CO_2/km	

[11] (Sundberg, 2009, pers. comm)

[12] (Linnemann, 2003)

[13] Due to difficulty in obtaining truck capacity values from Kumasi, the values used here represent the range of truck capacities in a Philippine context (Nepomuceno & De Jonge, 2008).

[14] (Nepomuceno & De Jonge, 2008)

DAF_{comp}	25 km/truck	
$PE_{7,transp}$	**280 - 1100 tCO_2e**	$= (Q_{y,comp}/CT_{y,comp}) \cdot DAF_{comp} \cdot EF_{CO2}$

6.4. LEAKAGE EMISSIONS, LE

No leakage is assumed as described in chapter 4.4.

6.5. EMISSION REDUCTION, ER

A potential CDM project in Kumasi as described above would according to these calculations result in the values presented in Table 5, in line with Equation 1; $ER_y = BE_y - (PE_y + LE_y)$.

Table 5 Calculations of Emission Reduction over a period of seven years.

Baseline emissions, BE_7	133 000 – 144 000	tCO_2e
Project emissions, PE_7	280 - 1100	tCO_2e
Leakage, LE_7	0	tCO_2e
Emission reductions, ER_7	**132 000 – 144 000**	**tCO_2e**

Described as an annual mean value the emission reduction would be 19 000 – 21 000 tCO_2e or 0.02 Tg CO_2e.

6.6. CERTIFIED EMISSIONS REDUCTION (CER) CREDITS

The closing price on the secondary CER market was on the 24th of November 2009 €11.94 according to values provided by PointCarbon[15]. This means that the CERs potentially acquired during seven years of a running CDM project as described in this report (132 000 – 144 000 CERs) would in November the 24th 2009 have a value of 1.5 – 1.7 million Euros. In other words this result equals 0.6 € per tonne of solid waste.

6.7. SENSITIVITY ANALYSIS

To check the reliability in the results a sensitivity analysis was carried out on the baseline emission equation (Equation 2), since that equation is the dominating equation when it comes to the final results. The sensitivity analysis was performed in Microsoft Excel using the "what-if"-tool. Selected parameters were all adjusted by an increase and decrease by 20%, while all the other parameters remained unadjusted. This text is primarily focusing on the 20% of increase. The decrease is of similar nature but opposite and is for clarity not included in Figure 5.

The selected parameters, assumed to carry a measure of uncertainty, comprise; amount of daily waste to the landfill (DailyWaste), fraction of degradable carbon that can decompose (DOCf),

[15] PointCarbon is a provider of news, analysis and consulting services for European and global carbon markets. www.pointcarbon.com

fraction of degradable carbon in waste fractions (DOCfood, DOCgarden, DOCpulp, DOCtextiles, DOCwood), fraction of methane in solid waste disposal site gas (F), decay rate for the different waste types (kjFOOD, kjGARDEN, kjPULP, kjTEXTILES, kjWOOD), model correction factor φ (ModelCorrectionFactor), population growth (PopGrowth). In Figure 5 the result of the baseline emission calculation is presented where these parameters are one by one increased by 20% together with the case when no adjustments are done (ScenarioNoAdjustments), which represent the result of the baseline emission calculation presented in chapter 6.2.

The response in the result due to 20% increases and decreases of parameters outside the double sum of Equation 2 was of course exactly the same for all parameters. Since there is a linear relationship between these parameters and the result of the baseline emission equation, the result of these adjustments is equal to adjusting the result itself. Hence, increasing one of the parameters outside the double sum with 20% would result in,

133 000 · 1.2 = 160 000 tCO_2/7 years (Scenario 1) and
144 000 · 1.2 = 173 000 tCO_2/7 years (Scenario 2).

A decrease of 20% of the parameters outside of the double sum results in likewise in,

133 000 · 0.8 = 106 000 tCO_2/7 years (Scenario 1) and
144 000 · 0.8 = 115 000 tCO_2/7 years (Scenario 2).

These parameters represent the biggest impact on the result of the baseline emission calculation as can be seen in Figure 5 (DailyWaste, DOCf, F, ModelCorrectionFactor)

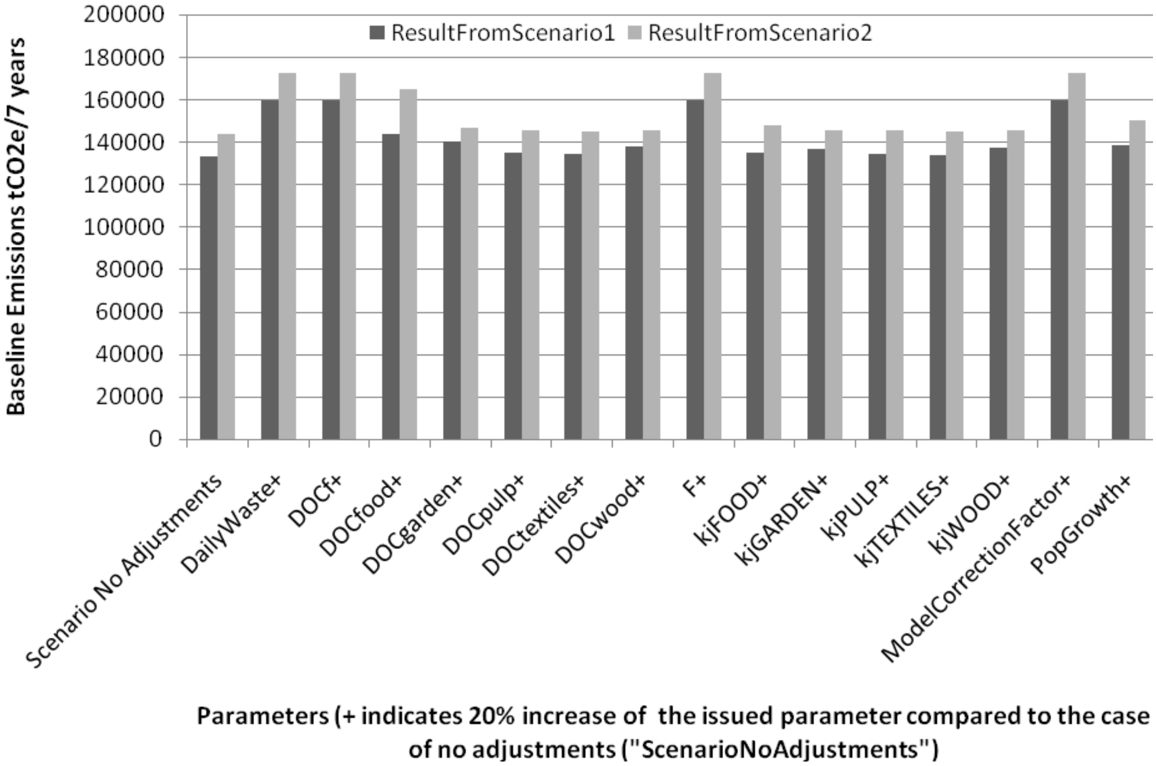

Figure 5 Result from sensitivity analysis of baseline emission calculation.

The response in the result due to adjustments of parameters inside the double sum differed between these parameters, but none of the responses from these adjustments was as big as for the parameters outside the double sum. The parameter "fraction of degradable organic carbon in food" (DOCfood) is the only one about to reach the same response as the parameters outside the double sum.

A result from this sensitivity analysis is thus that no exponential or similar behavior of the result of the BE calculation is expected due to any changes of the issued parameters. Changes of the parameters will only modify the result as for a first order equation. The model correction factor φ is itself a factor adjusting for uncertainty. This factor (0.9) is introduced to reduce the risk of overestimation of the BE.

7. DISCUSSION

In 2007, greenhouse gases[16] in the magnitude of 30 000 Tg CO_2e were emitted from anthropogenic sources of all Annex I countries and non-Annex I countries (UNFCCC Secretariat a, 2009) (UNFCCC Secretariat b, 2009), which can be used as an estimation of the total global anthropogenic GHG emissions. According to IPCC (2006) 5%, or consequently 1500 Tg CO_2e/year, of the total global anthropogenic GHG originates from the waste sector. The result of running the CDM-project issued in this report would after seven years result in an Emissions Reduction (ER_7) of 132 000 – 143 000 tCO_2 or 0,1 Tg/7 years. Per year this equals to 0.02 Tg and can be interpreted as the total annual mean GHG emissions from the Dompoase landfill during the first seven years period (2009 – 2015). Based on data from an approved Project Design Document[17] (Nepomuceno & De Jonge, 2008) of a similar CDM-project in the Philippines, a comparable value for the Emission Reduction of 0.018 Tg is estimated which indicate that this reports results lie within a reasonably correct order of magnitude (see appendix A 3 for details).

7.1. COMMENTS ON METHODOLOGY

How well does this model compute the GHG emissions? The methodology comprises measures to avoid methane emission to the atmosphere. Yet the greenhouse gas emissions from both compost and landfill include the greenhouse gas carbon dioxide. Even though the CO_2 is of biological origin, the amounts and timing of the CO_2 emissions have an influence on the atmospheric CO_2 levels. As the F-factor in Equation 2 illustrates, 50% of the solid waste disposal site gas consist of methane. The remaining 50% is mainly carbon dioxide (even in an anaerobic landfill) (Williams, 2005). The model however only takes carbon dioxide emissions into account when it comes to incremental transport distances and electricity and fuel consumption due to project facilities. No carbon dioxide from decomposition of organic waste is concerned. Based on the following reasoning there is a risk that the model is overestimating the GHG emission reduction achieved by the project. Assume two scenarios where waste containing two tonnes of degradable organic carbon is deposited at an anaerobic landfill as well as at a compost plant. At the landfill one tonne of the waste would in time become methane (CH_4) and one tonne become carbon dioxide (CO_2), assuming that the F-factor is 0.5, as in chapter 6.2. The result at the compost plant would instead be that all the two tonnes of degradable organic carbon in time would form CO_2. Hence, twice the amount of carbon dioxide as in the landfill scenario. It seems feasible that the one tonne of organic degradable carbon resulting in CO_2 at the landfill corresponds to one tonne of degradable organic carbon resulting in CO_2 at the compost plant in a way that they level out one another. When it comes to the tonne of organic degradable carbon

[16] The greenhouse gases included are: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydro-flour carbons (HFCs), Perflourocarbons (PFCs) and Sulphur hexafluoride (SF_6)

[17] A Project Design Document (PDD) is a document that the hosting and investing parties in a CDM-project compose that has to be approved by the Executive Board before a CDM-project can be started. The PDD describes how the parties have applied the methodology of the CDM-project (Michaelowa et al, 2007)

generating methane at the landfill, with a global warming potential (GWP) of 21 times the one valid for carbon dioxide, it seems reasonable though that this impact should be decreased by one unit, corresponding to the other tonne of organic degradable carbon generating carbon dioxide at the compost plant. By including this aspect in the system boundary the GHG emission reduction would be decreased by approximately 5% (6500 tCO_2e) over the seven year period, estimated through changing the GWP-value in Equation 2 from 21 to 1.

Another system boundary aspect is the compost product. In the model, the compost is outside of the system boundary as soon as it has been delivered 25 km away from the compost plants. In case this product would serve as a substitute for fertilizers, which required energy in its formation, an additional emission reduction could be achieved by a larger system boundary.

If the theory of increased global warming due to an increased concentration of greenhouse gases in the atmosphere is assumed to be valid, then having in mind that the lifetime of methane in the atmosphere is rather short (8 years) (Simpson et al, 2002) in comparison to carbon dioxide (5-200 years) (Archer & Brovkin, 2008) a question concerning prioritizations can be discussed. Seen in a short time perspective methane has great impacts in the atmosphere compared to carbon dioxide which may imply that more could be achieved in a short while by focusing on sources of methane emissions rather than sources of carbon dioxide emissions.

7.2. COMMENTS ON RESULT

The baseline emissions range from higher values in the case of larger fraction of food wastes in the organic waste (Scenario 2) to lower values where the food fraction is lesser (Scenario 1). Physically this can be interpreted as difference in the rate by which food, garden and wood waste is decomposing and thereby emitting methane. Mathematically it is motivated by the decay rates (k_j); 0.4; 0.17; 0.035 for food, garden and wood waste respectively.

Simplifications made in the report that deserve some comments would be the neglecting of the contribution to project emission (PE) from the new waste collection scenario due to the implementation of decentralized compost stations. Rather than increasing the waste transports and thereby the project emissions, a decrease of the transports seems feasible since only half of the waste deposited by the citizens at the waste stations (i.e. compost stations) has to be removed to a landfill, while the other half remains to be composted at the waste station site. If waste transports are decreased and thereby generate CERs to the project owners, it is obviously desirable for them to investigate this aspect further. If it is assumed that the result of such a further investigation would lead to a project emission in the same magnitude as is accounted for now, when transports of the compost product is included, the overall result of the total Emission Reduction would not be notably affected since the magnitude of the baseline emissions exceeds the project emissions by almost 1000 times.

Concerning compost stations, the result (Chapter 5) indicates that converting the former waste stations into compost plants, with the set-up as described, seem to result in a quite feasible amount of 3.6 tonnes organic waste to be handled at a daily basis (Rothenberger & Enayetullah, 2006). This circumstance implies that the citizens of Kumasi can continue to go to their accustomed place for waste dumping which would simplify the introduction and duration of the compost plants. There is a risk that the idea of converting the 124 waste stations into compost plants, that requires an average area of 1000 m^2 (see chapter 5), might encounter difficulties in its realisation due to lack of space. In many cases however, an informal dumpsite is situated in connection to the waste station and in that situation these sites together may encompass the area required. Less space is expected to be available centrally, while more can be assumed further from the city centre (Sundberg, 2009, pers. comm).

This study assumes no source separation of solid waste. Willingness among citizens in Kumasi to sort their household waste exists, though there is a path to go before it can be put to practise (Asase, 2008, Drechsel et al, 2004). Though source separation is preferable in order to reduce costs for the compost station and enhance working environment, it is not necessary in order to manage a compost station (Williams, 2005). Waste can be sorted by staff at the compost station.

Even though the CERs earned through transport reduction might not be many compared to the CERs earned from composting instead of landfilling, the reduction of transport costs it would result in are of great interest. A study of a compost plant in Accra, the capital of Ghana, indicates that transport costs are in the same magnitude as the expenditure for wages and salaries, or approximately 20% of that compost plant budget (Asante, 2008). This suggests that the transport expenses are both costly and extensive why a reduction in transport distances would be of great benefit.

Other benefits that are not accounted for in the project but nevertheless are desired is the decrease of landfill expansion due to slower filling, as a result of the composting of the organic waste fraction. This would prolong the lifetime of the landfill and postpone the siting of a new landfill. Even the health issue and odour dilemma with the landfill are also likely reduced since those aspects are tied closer with the organic fraction of the waste than with the inorganic.

7.3. FUTURE STUDIES

Future studies, in order to approach a realisation of a CDM project in Kumasi as presented in this study, must involve an economical evaluation. The aspect of additionality, where for instance financial and project prevailing barriers must be proven (see chapter 3.5), remains to be examined. It seems possible though, based on the waste management challenges Kumasi encounters today, that such a project could be agreed on seen from an economical point of view. Composting itself is not likely to be a lucrative business since fertilizers from Kumasi's many poultry farms are readily available for free (Drechsel et al, 2004), implying that composting needs subsidies and therefore is not something that easily would have happened without a CDM project.

8. CONCLUSION

A potential CDM project, as it has been outlined in this report, could reduce the greenhouse gas emissions (preferentially methane), that in present situation are emitted from the Dompoase landfill, by a mean of 19 000 – 21 000 tCO_2e every year. This would generate secondary Certified Emission Reduction credits of an amount of approximately annual mean of 230 000 – 250 000 Euros with November 2009 market prices.

The suggested reformation of the waste management, converting the 124 of Kumasi's waste stations into decentralised compost plants would imply a daily treatment of approximately 3.6 tonnes of organic waste at each station.

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A APPENDIX

A 1 BASELINE EMISSION CALCULATION

Below follows the calculation of the baseline emissions for Scenario 1. Hence scenario 2 is not presented but calculated likewise based on values for scenario 2 in table 3 in the report.

Estimation of solid waste per capita and day deposited on Dompoase landfill needed for further calculations is accounted for in Table 1.

Table 1 Estimation of solid waste per capita deposited at Dompoase landfill.

Entities (units)	Values	Source/comment
Daily total waste to landfill (tonnes)	900	(Adjei-Boateng, pers. comm)
Estimated population in 2009	1878241	(Erni et al, 2007)
Waste per capita to landfill (kg/day)	0.48	From above

For technical reasons the baseline emission expression (Equation 2 in the report) is divided into two parts; BE_a and BE_b (and renamed Equation A1):

$$BE_{CH4,SWDS,y} = \underbrace{\varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF \cdot}_{BE_a} \underbrace{\sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j (y-x)} \cdot \left(1-e^{-k_j}\right)}_{BE_b} \quad (A1)$$

In Table 2 the amount of organic waste type j prevented from disposal in the SWDS in the year x ($W_{j,x}$) is calculated where each step in is described in the table heading. In this table a population growth of 5.4% is accounted for. The waste fractions ($P_{n,j,x}$) refer to Table 3 in the report and are compiled so that sum of all organic fractions equals 1.

Table 3 pictures the calculation of BE_b, where the result is named "Sum of column ΣΣ". The Wj,x column in Table 2 is the same as in Table 3 disregarded that the entire Wj,x column in Table 3 is multiplied by 1.01^x to account for the waste management improvement described in chapter 6.3 in the report. y is the number of years reflecting the first seven years of the CDM-project

Table 2 Calculation of $W_{j,x}$ (Amount of organic waste type j prevented from disposal in the SWDS in the year x (tonnes))

j Organic Waste Categories	**Year**	**Population** - with 5,4% growth rate/year (see Table 1)	**Waste to landfill** (tonnes/day) [Population*0.48 (see Table 1)*0.001]	**Organic waste to landfill** (tonnes/year) [Waste to landfill*365*0.5 (since 50% organic waste)]	**Scenario 1 Pn,j,x** - Waste fractions from Table 4 in report - adjusted so that only the organic fraction is considered	**Scenario 1 W *j,x*** *(tonnes/year) [Pn,j,x * Organic waste to landfill]*
Wood	2009	1878241	900	164250	0.258	42366
Pulp	2009	1878241	900	164250	0.062	10103
Food	2009	1878241	900	164250	0.357	58661
Textiles	2009	1878241	900	164250	0.063	10429
Garden	2009	1878241	900	164250	0.258	42366
Wood	2010	1979666	949	173120	0.258	44654
Pulp	2010	1979666	949	173120	0.062	10648
Food	2010	1979666	949	173120	0.357	61828
Textiles	2010	1979666	949	173120	0.063	10992
Garden	2010	1979666	949	173120	0.258	44654
Wood	2011	2086568	1000	182468	0.258	47065
Pulp	2011	2086568	1000	182468	0.062	11223
Food	2011	2086568	1000	182468	0.357	65167
Textiles	2011	2086568	1000	182468	0.063	11585
Garden	2011	2086568	1000	182468	0.258	47065
Wood	2012	2199243	1054	192321	0.258	49607
Pulp	2012	2199243	1054	192321	0.062	11829
Food	2012	2199243	1054	192321	0.357	68686
Textiles	2012	2199243	1054	192321	0.063	12211
Garden	2012	2199243	1054	192321	0.258	49607
Wood	2013	2318002	1111	202707	0.258	52285
Pulp	2013	2318002	1111	202707	0.062	12468
Food	2013	2318002	1111	202707	0.357	72395
Textiles	2013	2318002	1111	202707	0.063	12870
Garden	2013	2318002	1111	202707	0.258	52285
Wood	2014	2443174	1171	213653	0.258	55109
Pulp	2014	2443174	1171	213653	0.062	13141
Food	2014	2443174	1171	213653	0.357	76305
Textiles	2014	2443174	1171	213653	0.063	13565
Garden	2014	2443174	1171	213653	0.258	55109
Wood	2015	2575105	1234	225190	0.258	58085
Pulp	2015	2575105	1234	225190	0.062	13851
Food	2015	2575105	1234	225190	0.357	80425
Textiles	2015	2575105	1234	225190	0.063	14298
Garden	2015	2575105	1234	225190	0.258	58085

Table 3 Calculation of BE_b, where the result is named "Sum of column ΣΣ".

j Organic Waste Categories	**W j,x** (tonnes) Values from Table 2, Appendix 1 but multiplied by 1.01^x (see chapter 6.3. in report)	**DOCj** (wet weight) (see Table 2 in report)	**kj** Decay rate (see Table 2 in report)	**x**	**Column ΣΣ Calculation of Be_b in Equation A1** (y = 7 years)
Wood	42366	0.43	0.035	1	508
Pulp	10103	0.4	0.07	1	180
Food	58661	0.15	0.4	1	263
Textiles	10429	0.24	0.07	1	111
Garden	42366	0.2	0.17	1	478
Wood	45100	0.43	0.035	2	560
Pulp	10755	0.4	0.07	2	205
Food	62447	0.15	0.4	2	418
Textiles	11102	0.24	0.07	2	127
Garden	45100	0.2	0.17	2	603
Wood	48011	0.43	0.035	3	617
Pulp	11449	0.4	0.07	3	234
Food	66477	0.15	0.4	3	664
Textiles	11818	0.24	0.07	3	145
Garden	48011	0.2	0.17	3	761
Wood	51110	0.43	0.035	4	681
Pulp	12188	0.4	0.07	4	267
Food	70767	0.15	0.4	4	1054
Textiles	12581	0.24	0.07	4	165
Garden	51110	0.2	0.17	4	960
Wood	54408	0.43	0.035	5	750
Pulp	12974	0.4	0.07	5	305
Food	75335	0.15	0.4	5	1674
Textiles	13393	0.24	0.07	5	189
Garden	54408	0.2	0.17	5	1211
Wood	57920	0.43	0.035	6	827
Pulp	13812	0.4	0.07	6	348
Food	80197	0.15	0.4	6	2658
Textiles	14257	0.24	0.07	6	216
Garden	57920	0.2	0.17	6	1528
Wood	61658	0.43	0.035	7	912
Pulp	14703	0.4	0.07	7	398
Food	85373	0.15	0.4	7	4222
Textiles	15177	0.24	0.07	7	246
Garden	61658	0.2	0.17	7	1928
			Result/Sum of column ΣΣ:		**26411**

$$BE_{CH4,SWDS,y} = \underbrace{\varphi \cdot (1-f) \cdot GWP_{CH4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_f \cdot MCF}_{BE_a} \cdot \underbrace{\sum_{x=1}^{y} \sum_{j} W_{j,x} \cdot DOC_j \cdot e^{-k_j (y-x)} \cdot \left(1-e^{-k_j}\right)}_{BE_b} \quad (1)$$

Finally, Equation A1 can be calculated inserting the values for BE_a found in Table 1 in the report multiplying BE_a with BE_b (in other words "Sum of column ΣΣ");

BE_7 (scenario 1) = BE_a * BE_b = 5.04*26411 = 133000 tCO_2e.

A 2 DECAY RATE ASSESSMENT

Assessment of decay rate, k_j, for the waste type *j*.

Based on information from climate data for Kumasi such as mean annual temperature, MAT mean annual precipitation, MAP and potential evapotranspiration, PET, decay rates, k_j, for waste types *j* are assessed through the default values in Table 1 provided from UNFCCC.

MAT for Kumasi calculated from the years 1960 – 2003 (IWMI, 2008) 26.2˚C

MAP for Kumasi calculated from the years 1961 – 2003 (IWMI, 2008) 1375 mm

Table 4 Default values on decay rate, k_j, for waste types j, as a function of climate.

Waste type *j*		**Boreal and Temperate (MAT≤20°C)**		**Tropical (MAT>20°C)**	
		Dry (MAP/PET <1)	Wet (MAP/PET >1)	Dry (MAP< 1000mm)	Wet (MAP> 1000mm)
Slowly degrading	Pulp, paper, cardboard (other than sludge), textiles	0.04	0.06	0.045	0.07
	Wood, wood products and straw	0.02	0.03	0.025	0.035
Moderately degrading	Other (non-food) organic putrescible garden and park waste	0.05	0.10	0.065	0.17
Rapidly degrading	Food, food waste, sewage sludge, beverages and tobacco	0.06	0.185	0.085	0.40

NB: MAT – mean annual temperature, MAP – Mean annual precipitation, PET – potential evapotranspiration. MAP/PET is the ratio between the mean annual precipitation and the potential evapotranspiration.

Hence, since MAT is over 20˚C and MAP is over 1000mm the decay rates are:

Pulp, paper, cardboard 0.07; Wood, woodproducts and straw 0.035; Other orbanic putrescible garden and park waste 0.17; Food, food waste, sewage sludge, beverage and tobacco 0.40

A 3 COMPARISON WITH PHILIPPINE STUDY
Comparison to a Philippine CDM-project

The comparison of the Kumasi project with a Philippine project (Nepomuceno & De Jonge, 2008) is done below through calculating the mean emission reduction per capita in a municipality that is a part of the Philippine study and thereafter applies this value on the Kumasi population.

According to the Project Design Document for a Philippine study a municipality called San Pedro (GMA), populated by 145382 people, was estimated to generate emission reductions (ER) as presented in Table 1 below.

Table 1 Emission Reduction in a Philippine study of San Pedro municipality

Year	Emission Reduction , ER [tCO_2]
2008	379
2009	705
2010	985
2011	1234
2012	1465
2013	1686
2014	1902

An annual mean emission reduction over the time frame described in Table 1 results in:

1194 tCO_2e

The mean emission reduction per capita is therefore:

1194/145382 = 0.00821 tCO_2e/capita

The mean population in Kumasi for the time frame of the CDM-period presented in this report (2009-2015) is estimated to 2 211 000 people (see chapter 1.1.1.)

Using the annual mean emission reduction per capita for the Philippine study multiplied with the estimated mean population in Kumasi (2009 – 2015) following emission reduction would be relevant in the Philippine context with a population as in Kumasi:

0.00821 tCO_2e/capita · 2 211 000 capita = 18 100 tCO_2e = 0.018 Tg CO_2e