Technische Universität Hamburg-Harburg

Design of a supply chain for a sustainable sanitation system on the example of Accra and Kade, Ghana

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To my beloved wife, our wonderful family and God

Declaration

I hereby declare that I am the sole author of this thesis. Furthermore, I swear that this document is my own original work and that no part of it has been submitted to any other institute in this or any deviated manner. All literal content and quotations from other sources are clearly pointed out and no other sources than those declared have been used.

Ivan Francisco Martinez Neri

Hamburg, Germany, 2nd of November, 2009.

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Abstract

The lack of improved sanitation facilities in Ghana has led to pollution of its water bodies and open spaces due to improper disposal of human waste. At the same time, urine and faeces contain the nutrients that were taken away from the soils when food was grown. As these excreta is disposed in a different place other that the origin of its nutrients, the soils are in a serious state of depletion. Studies have been carried out to implement the Ecological Sanitation (ecosan) concept in the city of Accra and various models have been suggested. However, their implementation is constrained by the rejection that the society may have regarding the use of excreta as a fertilizer in agriculture and also by the huge logistics costs that the transport of urine implies. This thesis studies the feasibility of implementing a large-scale ecosan based sanitation system, by exploring different configurations of the supply chain intended to collect, transport and use sanitized human excreta as a fertilizer. The analysis is executed in the city of Accra and in the semi-urban settlement of Kade. The resulting model consists of a supply chain where the cargo capacity of the vehicles used to transport human excreta along the supply chain is efficiently used, thus decreasing or even eliminating the costs of transportation. In addition, the risk of social rejection to this sanitation approach is reduced by using the treated excreta for producing a sort of widely demanded biomass-based fuels, such as biodiesel, charcoal and fuel wood. Finally, the analysis of groups and individuals that are likely to be affected by the implementation of the project is carried out. The results show that there is enough interest and commitment to start implementing the project in the short term.

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Acronyms

ARS – Agricultural Research Station of the University of Ghana in Kade

CBD – Central Business District, Accra

CIF – Cost Insurance and Freight

CWIQ – Core Welfare Indicators Questionnaire

Ecosan – Ecological Sanitation

EFB – Empty Fruit Bunches

EPA – Environmental Protection Agency, Ghana

FAO – Food and Agriculture Organization of the United Nations

FFB – Fresh Fruit Bunches

GDP – Gross Domestic Product

GEC – Ghana Energy Commission

GH¢ – Ghanaian Cedi. Exchange rate as of September 2009, GH¢ 2.0 = € 1.0 = US$ 1.5

GNA – Ghana News Agency

GOPDC – Ghana Oil Palm Plantation Development Company

GTZ – Deutsche Gesellschaft für Technische Zusammenarbeit

IDRC – International Development Research Centre

IWMI – International Water Management Institute, Ghana

KVIP – Kumasi Ventilated Improved Pit

MOFA - Ministry of Food and Agriculture in Ghana

NPK – Nitrogen-Phosphorus-Potassium fertilizer compound

NCRC – Nature Conservation Research Centre

SSA - Sub-Saharan Africa

UDT – Urine Diverting Toilet

UDDT – Urine Diverting Dehydration Toilet

UNDESA – United Nations Department of Economic and Social Affairs

UNEP - United Nations Environment Programme

UN – United Nations

VVU – Valley View University, Ghana

WHO – World Health Organization

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1 Introduction

Today, at the beginning of the 21st century we have experienced development in many areas at a pace that could have never been imagined one hundred years ago. However, despite all this advance in some fields, in others, such as sanitation, the development is not impressive at all. Today, 2.5 billion people on the planet still lack a decent facility for fulfilling their most basic sanitation needs.

In most of the developed world, and in a considerable part of developing countries, it has been promoted that waterborne sanitation systems are symbols of well-being and progress of the society. But the facts show that this assumption is quite deviated from reality.

The so-called modern sanitation systems have led to two of the worst environmental degradation problems that we face today. Firstly, they have caused the depletion of soils through improper relocation of nutrients that were extracted from them to produce food. Secondly, they cause the discharge of all these nutrients into rivers and oceans where they do not belong, thereby breaking the natural balance of water bodies and soils affecting life which develops there and that at the end is also a source of food for humankind.

The most natural way of recycling the nutrients is to let them be reincorporated into the place from where they were taken. Leaves fall from trees to be degraded and then reabsorbed in the soil so their forming elements can be used again as a part of the ecosystem. Mammals, birds, insects and mostly any kind of living organisms have evolved and survived thanks to their ability to adapt to the natural rhythm of recycling nutrients that they took from the environment in where they develop.

Is it that simple? Yes. Typically followed? Sadly, no.

Humans do it the other way around. First, nutrients are taken from soils, then disposed into the oceans. After that, minerals are taken from other parts of the world and transported to be used as a source of nutrients on lands that are gradually becoming devoid of them. Each unit of nutrient taken form the soil is one less unit of a finite pool of elements that sooner or later will become completely exhausted.

In light of this situation it is worth to ask: is there a system that could emulate the loop that nature follows with nutrients and to recycle human excreta in a completely safe way? And if such system already exists, what are the challenges and limitations that have to be overcome in order to implement it on a large scale in the regions of the world where it is needed the most?

Today, we must change the paradigm imposed by the waterborne sanitation systems, which perceive human waste as a hazardous material that needs to be taken away from human settlements. It is time to shift the way in which society perceive excreta. It is time to think in terms of more than one solution to solve "our sanitation needs", because with the methods that we have followed until today, these have become "our sanitation problems".

1.1 Problem statement

Previous research has found that the use of treated human excreta in Ghana as a fertilizer is limited by the social perception of this practice and also by the costs incurred in its collection, transport, treatment and application in the crop fields (Tettey-Lowor, 2008; Stoll, 2008; Danso et al., 2004). The state of sanitation in Ghana is fairly underdeveloped. The wastewater disposal and treatment infrastructure is not sufficient to cope with the amount of human excreta generated within the cities, which has lead to heavy contamination of open spaces inland water bodies and the sea (Owusu-Boadi, 2002). At the same time, agriculture performs well below its optimum level because of the high costs of fertilizer and fuel (Diao et al., 2007). These both circumstances have deep implications on the Ghanaian population, such as low income from agricultural activities and high incidences of death due to proliferation of waterborne diseases, like cholera, diarrhoea, worm infestations or hepatitis (WHO, 2008). Up to date, no study has found a way to properly collect, transport and use treated human excreta as a fertilizer without being limited by economic and social constrains.

1.2 Purpose of the study

The goal of this thesis is to design a supply chain for the collection, transport, treatment and use of human excreta generated in urban and rural settlements of Ghana and thereby to avoid the undesired effects derived from improper disposal of this material.

1.3 Significance of the study

The importance of this study lies in the urgent need to find a proper way for disposing the large amounts of human excreta generated in urban and rural settlements in low-income regions. The sanitation problems found in Ghana are similar to the existing ones in most developing countries. If there is a suitable solution involving low investment and simple technology, it has the potential of being replicated, thereby solving some of the most vital problems of our society, such as the adequate provision of improved sanitation and reduction in deaths related with preventable diseases.

1.4 Research questions

In the light of the above considerations, this thesis has the following objectives:

1.To identify the main limitations for using human excreta as a fertilizer in Ghana

2.To study solutions given in previous research

3.To suggest appropriate solution in the light of the identified constraints and deficiencies

2 Background

In this chapter, a review of existing literature is carried out to determine the state of knowledge in the fields that are going to be addressed in the development of this work. The first part presents an overview of waterborne sanitation systems, which are mostly used in the developed world, and the drawbacks that they might have if applied in parts of the world where such systems do not exist. Following, the ecological sanitation approach is introduced and its advantages and challenges described. The explanation of how important fertilizers are in agriculture together with the positive and negative impacts of its use are covered in the third part of the section. The fourth part gives an overview of the state of sanitation and fertilizers use in Ghana and the particular situations of Accra, the capital city of Ghana and Kade, a semi-urban location in the Eastern Region. Both are analysed to propose a solution that could fully integrate the urban and rural settlements of the country in the implementation of a large-scale ecological sanitation system. Finally, an overview of the palm oil and biodiesel industries is presented, as these elements will be integrated in the supply chain that is proposed later in this work.

2.1 Sanitation - historical perspective and overview

Prior to waterborne sanitation systems the most practised way of disposing human excreta was either just throwing it away in the fields and streets or collecting it for its further use in agriculture. In most human settlements this practice almost seized some hundred years ago due to the fast growth of cities and the resulting lack of space. In addition, mineral fertilizers became widely available and people stopped using human faeces as a source of nutrients for their crops.

In Japan, human excreta had been used as a fertilizer since ancient times. It was after the Second World War that they decreased the use of night soil to fertilize their orchards. The main reason for this was the attitude of the American occupying force, which regarded that practice as unhygienic and ordered their soldiers not to eat vegetables grown in local farms (LIFE, 1945).

In China, human waste has been used as a fertilizer for thousands of years either alone or in combination with another kind of organic waste. The ancient society realized that the use of this kind of manure increased their yields and maintained the soil's fertility. On the contrary to the Japanese example, the Chinese population still uses human faeces as a fertilizer. Even tough between the 50s and the 1980s the use of mineral fertilization increased in that country, the use of animal and human waste was not neglected, but even increased (Yuan, 1984). Certainly, these practices have prevented soil degradation, especially taking into account the thousand of years of constant farming in that country.

In waterborne sanitation systems used today, the volume of human excreta is increased up to forty-fold because of its dilution with water (Otterpohl, 2001). Table 1 illustrates the characteristics of wastewater flows with no dilution of urine and faeces. In addition, it can be observed that even if urine accounts for a small fraction of the volume of domestic wastewater, it contains most of the nutrients of all streams.

The dilution of excreta makes its posterior use as a fertilizer impractical and increases the difficulties for its storage and transportation. Instead of closing the loop of sanitation by replacing the nutrients that were extracted from agricultural soils, traditional wastewater networks are mostly linear. They take nutrients from the soil and dispose them into water bodies. What makes matters worse, they use clean water to do all this process.

Table 1: Nutrients contained in domestic wastewater flows with no dilution for urine and faeces, adapted from Otterpohl (2001)

	Greywater	Urine	Faeces
Yearly load kg/(person*year)	24,000 – 100,000	~ 500	~ 50
Nitrogen	~ 3%	~ 87%	~ 10%
Phosphorus	~ 10%	~ 50%	~ 40%
Potassium	~ 23%	~ 60%	~ 17%

The objective set by the United Nations (UN) in the Millennium Development Goals is to halve the proportion of people without access to basic sanitation and safe drinking water by 2015 (UN, 2008). If this goal is to be achieved, it can not be done taking only into account the conventional waterborne sanitation system. It would be contradictory to bring western-style sanitation at the cost of polluting the sources of water and dilapidating the mineral resources of soils in developing countries.

In addition, conventional water and sewage networks are costly and most developing countries might find it difficult to finance and maintain them. Even if there were enough resources to finance one of such systems, there is no way to prove that they are going to be sustainable.

As it can be observed in Figure 1, sewage treatment varies considerably among different regions of the world. In some of them the discharge of untreated wastewater has been reduced significantly, such as the North Atlantic region with just 10%, but others are still discharging more than 80% of their wastewater into the oceans (United Nations Environment Programme [UNEP], 2006).

The increase of chemical nutrients present in water bodies, particularly nitrogen and phosphorous, has lead to the proliferation of the so called “dead zones”, which are areas of oceans and lakes deprived of oxygen that cannot sustain life for as long as the excess of nutrients is not dispersed or removed. The quantity of these zones have doubled since 1990 and the main cause is not only the discharge of untreated wastewater from coastal urban zones, but also the excessive use of fertilizers in intensive agricultural activities (UNEP, 2006).

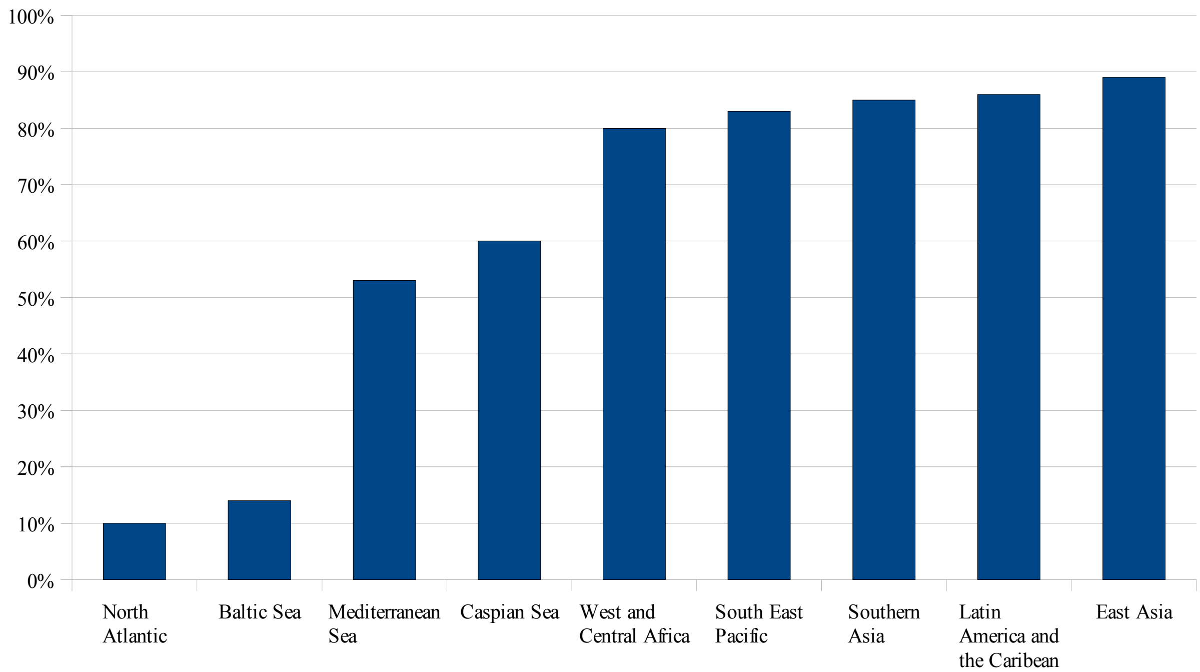

Figure 1: Percentage of wastewater that is discharged untreated (UNEP, 2006)

Currently, the application of fertilizers exceeds agronomic needs in most countries in the world where they are employed. The use efficiency of nitrogen, expressed as grain production per unit of nitrogen applied, has been decreasing, reflecting an over-use of this nutrient and the increase in nitrate concentrations in surface and groundwater. When these concentrations are high in the sources of drinking water it can cause serious health problems (Hatfield et al., 2004; Werner, 2006).

Even if nutrients contained in wastewater can be recovered by using treated sewage sludge as a fertilizer, it has to undergo a series of chemical processes, e.g. nitrogen removal, which reduce its fertilizer value. At the end just a small fraction of nutrients that might be recovered is reintroduced into the soil (Werner, 2006).

Another method of sanitation that potentially pollutes water bodies are so-called pit latrines. This method of collecting human waste basically consists of a shallow trench in the ground. In these latrines the solid matter of excreta is retained in the pit, but the liquid part is infiltrated into the subsoil, which might pollute the ground and underground water bodies. Other disadvantages of this sanitation method include bad smell, the fact that they nest flies and insects and that its location outside the house might be problematic for using it at night, especially for women, children and elderly (Werner, 2006).

Open defecation is a poor hygiene habit that is still widely used in the world today. This practise threatens not just the individual doing it but also its entire community, because it leads to the dissemination of preventable diseases, such as cholera, diarrhoea, worm infestations or hepatitis (UN, 2008).

Each year 5 billion cases of diarrhoea occur in developing countries. This disease alone is responsible for 16% of the deaths among children under the age of five in the sub-Saharan region of Africa (SSA) (WHO, 2009). It has been estimated that universal access to an improved sanitation facility could reduce up to 7% (or US$1.6 billion) of the annual health budget in developing countries. Just by providing access to toilet facilities in SSA the risk of diarrhoea could be reduced by 50% if it is by means of a flush toilet or by 30% if a pit latrine is used (Watkins, 2006).

As it can be observed in Figure 2, even tough in SSA the proportion of population using an improved sanitation facility has increased by 19% between 1990 and 2006, to accomplish the target of the MDG by 2015, these fraction should increase by 100% (UN, 2008).

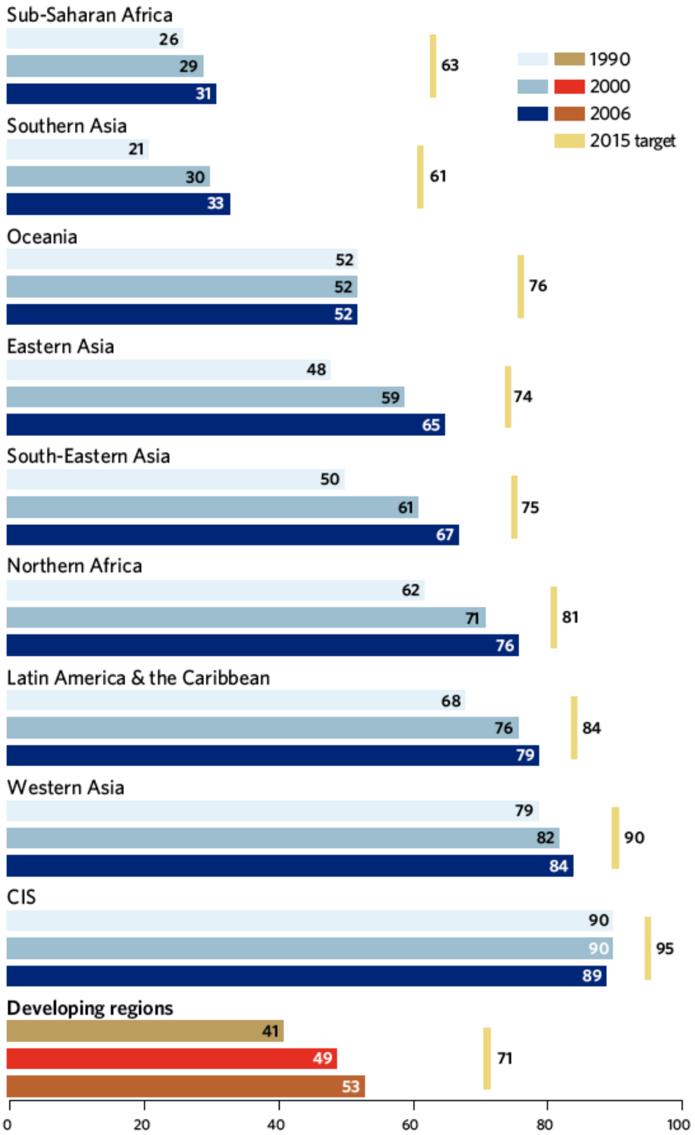

Figure 2: Proportion of population using an improved sanitation facility (percentage) (UN, 2008)

As it can be observed, the current state of sanitation in the world presents two main challenges: first, to halve the global population without access to proper sanitation, and second, the conventional sanitation approach considered as "modern" and as a model to follow is most of the times unsustainable.

All regions without current access to proper sanitation still have the opportunity to adopt a more ecologically oriented sanitation approach. This can be done without bearing the switching costs that might be incurred by replacing waterborne systems with a better system in which little or no water is needed. It is time to focus on other low-cost systems that have demonstrated to fulfil the need of sanitation in almost any region in the world and which do so in a sustainable way that guarantees the recirculation of nutrients back to the soil.

2.2 Ecological sanitation

2.2.1 The ecological sanitation approach

The basic principle of the ecological sanitation approach (ecosan) is to close the loop between sanitation and agriculture by not considering human faeces and urine as a waste, but as a valuable resource that must be recovered for its posterior use. Implementation of the ecosan concept reduces health risks related to sanitation by providing a framework for proper collection and treatment of human excreta (Werner, 2006).

2.2.2 Ecosan technology

As it can be observed in Figure 3, there is no specific technology attached to the ecosan approach. Multiple methods for collecting, treating and reusing urine and faeces following this sanitation concept are used in different projects around the world.

Among all the available ecosan technologies, this work is focused on those related to urine diversion and dehydration toilets. These techniques are based on the separate collection of urine and faeces at source and its posterior use as fertilizers. The collection and treatment of solid biowaste, greywater and rainwater will not be discussed in this thesis.

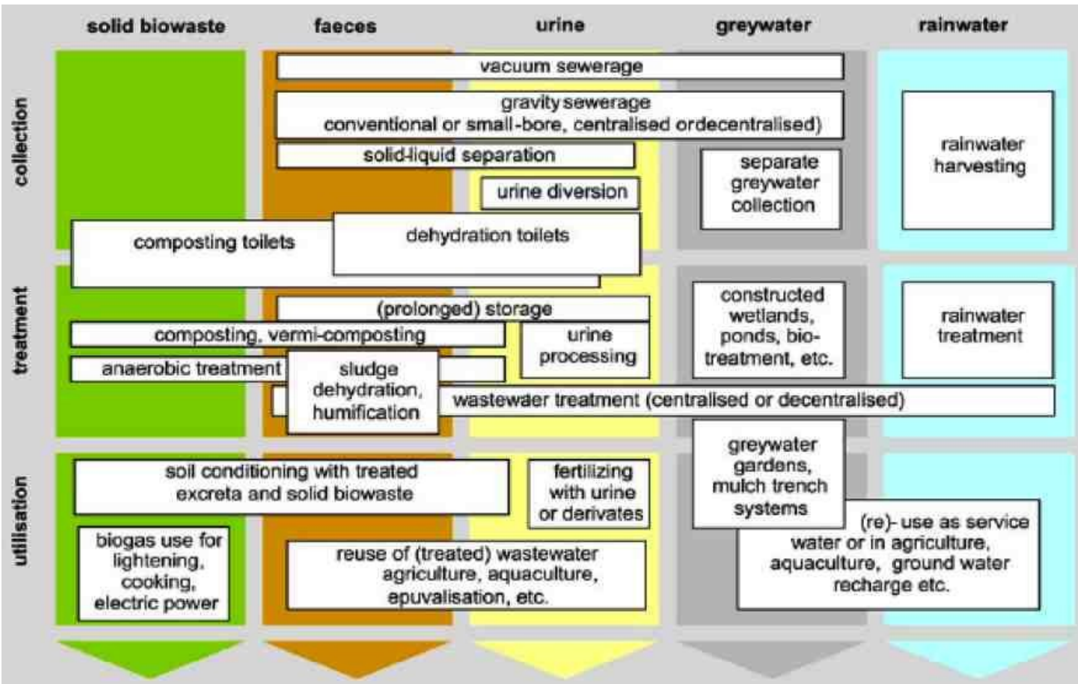

Figure 3: Technological components used in ecological sanitation (Rüd et al., 2008)

A urine diverting toilet (UDT) is designated to separate urine at source. In this kind of toilets faeces are still flushed with water, but urine stream is directed to a container where it is stored for its posterior treatment and use. The following figure illustrates one of such toilets:

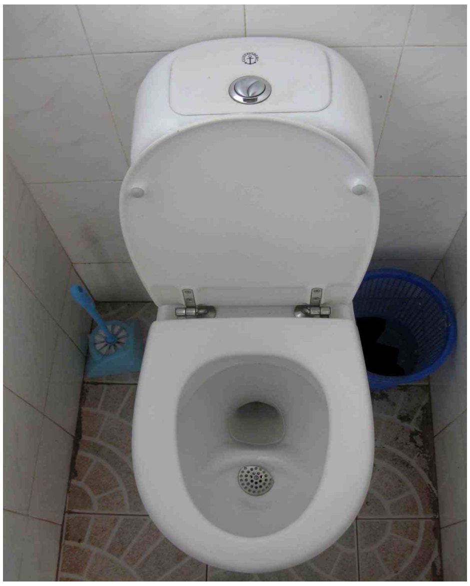

Figure 4: Urine diverting toilet at Valley View University, Ghana

On the other hand, in urine diverting dehydration toilets (UDDT), faeces are not flushed with water, but contained inside a vault or ventilated chamber where they are left to dry. Figure 5 illustrates the basic principle of an UDDT.

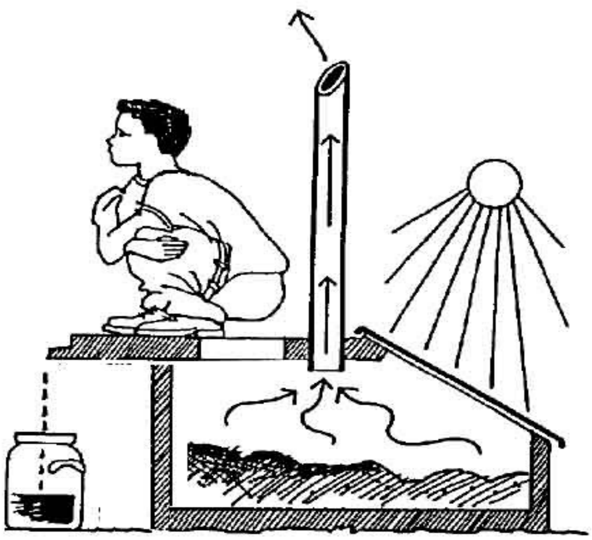

Figure 5: Urine diverting dehydration toilet, adapted from Esrey et al., (1998)

As it will be described in detail later, the separate collection of urine and faeces helps to optimise their posterior use by minimizing or avoiding the unnecessary dilution that makes the transport of the mixture difficult. Another important reason for which the collection of urine and faeces must be done separately is that, despite the sterile nature of urine excreted from a healthy person, it can become contaminated with bacteria if it gets in contact with faeces. In fact, misplacement of faeces in the container assigned to urine will undermine the potential use of it as a fertilizer. For this reason, adequate explanation for the intended users of this technology is of vital importance for the successful implementation of this concept.

2.2.3 Hygienization of urine and faeces

After urine and faeces are properly collected, they must follow a further treatment before they can be used as a source of nutrients in agriculture.

In the case of urine, the treatment consists of storing it in a sealed container. The temperature at which this storage takes place plays an important role in the time that it will take for urine to be safe to use as a fertilizer. The effect of the temperature, ammonia production and elevated pH (9) inactivate the microorganisms that might pose a risk for use of urine as a fertilizer. Table 2 shows the effects of storage time and temperature on urine that must be taken as a guideline for its proper hygienization.

Table 2: Relationship between storage conditions, pathogen content of the urine mixture and recommended crop, adapted from Höglund, (2001)

Storage temperature	Storage time	Possible pathogens in the urine mixture	Recommended crops
4°C	≥1 month	viruses, protozoa	food crops that are to be processed, fodder crops
4°C	≥6 months	viruses	
20°C	≥1 month	viruses	
20°C	≥6 months	probably none	all crops

Apart from isolating urine for its hygienization, the storage in a sealed container is important for preventing the evaporation of ammonia, a valuable source of nitrogen, which plays a crucial role in the fertilization of plants. This aspect will be explained in detail in the following section.

In the case of faeces, after they fall into a depository (chamber, bucket, plastic container, etc.) lime or wood ashes have to be added to elevate the pH and help to eliminate the pathogens present. The addition of this material also covers the surface of faeces, helping to decrease the moisture content and the odour that attracts flies (Boost et al. 1998). Depending on the method used for the posterior treatment of faeces, this depository could be removed and transported to a composting site or the filled container could be settled apart to allow the dehydration of the faeces.

2.2.4 Use of urine and faeces as fertilizers

After following the storage time recommended in Table 2, the application intervals of urine in the field could follow the same criteria as mineral fertilizers. As it will be further explained in Section 2.2.6, the plant availability of the nitrogen contained in urine has been proved to be the same as chemical urea or ammonium fertilizers. Even if many crops prefer ammonium nitrate, urine applied to the soil will be transformed into it due to microbial activity (Jönsson, 2004). Urine has to be applied close enough to the ground to avoid aerosol and it is also recommended to flush it into the soil by using water or by incorporating it with a shovel or another mechanical device.

In any case, it must be taken into consideration that ammonia present in urine could burn the plants if applied directly, therefore it is recommended to dilute urine with water (4:1). Also, it is suggested to apply it a few days before the seeding. For the use of urine after the plants have grown it must be applied to a distance at which the plant avoids direct contact but close enough for its roots to reach it.

Urine can also be used as a source of complementary nitrogen in composts where, due to the nature of its constitution, nitrogen's deficiency occurs. Also it needs to be considered that the ratio of the nutrient's content in urine varies widely and it may not correspond to the needs of the crops where it is intended to be used. This can lead to under- or over-fertilizations, which depending on the climate may end up accumulating salts that can harm the crops and the soil.

For the use of urine and faeces the farmer should wear gloves and take any precaution related to the handling of potentially infectious materials. After the application has taken place, hand washing should be always done and it is recommended to wait at least one month for harvesting the products.

2.2.5 Closing the loop of sanitation

After the application of treated urine and faeces, the loop of sanitation is finally closed. The nutrients that were taken away from the soil are replaced. The following figure illustrates the nutrient flows in the conventional and the ecological sanitation approaches.

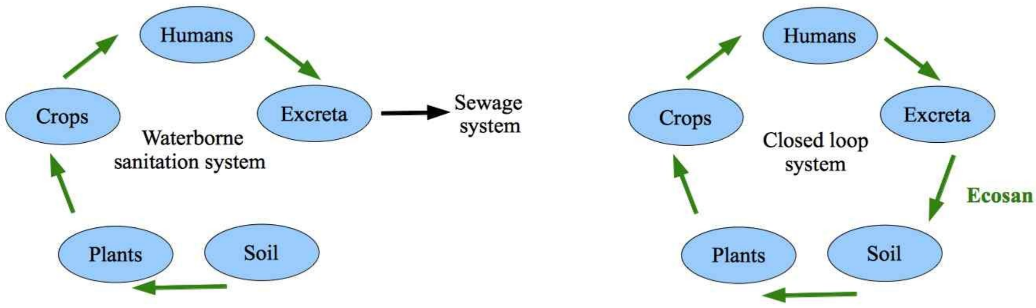

Figure 6: Nutrient flows in waterborne and ecological sanitation approaches

It is evident that the solution that has been used and promoted as the symbol of modernization does not make any sense for the sustainability of the environment. The open loop system wastes precious resources such as water and nutrients and provides unsustainable sanitation. The ecosan based system derives into proper ecological and sustainable sanitation and helps to maintain the soil's fertility, while at the same time helps to provide food to people who need it the most.

2.2.6 Implementation of the ecosan approach

Many challenges have been identified as the most important factors needed to be overcome in order to achieve a successful introduction of the ecosan concept (Rüd et al., 2008; Leinert et al. 2003), and although this form of sanitation presents many advantages, there are also many difficulties that impede its immediate adoption in the regions where it is most needed. Among the important challenges to be overcome are:

–Social acceptance

–General awareness among the decision-makers of the society

–Political commitment

–Promotion and marketing

–Cultural constraints regarding the use of excreta

–Infrastructure development for the collection, treatment and reuse of the excreta

–Guarantee the safety

–Financing

One aspect that has raised more concerns is the one regarding to the safety of urine to be used as a fertilizer, since farmers are worried about the presence of micropollutants or hormonal residues (Leinert et al. 2003; Tettey-Lowor, 2008). Regarding this concern, it has been found out that in the manure of domestic animals, which is extensively used as an organic fertilizer, the concentration of hormones is much higher than those present in human urine (WHO, 2006).

Other challenge that must be solved is that the ecosan approach has to convince the intended users that the fertilization potential with treated urine and faeces is equivalent to the mineral one.

Many ecosan projects have been implemented in different parts of the world, and their results confirm that the effectiveness of the treated excreta is not questionable. In various experiments carried out in seven West African countries between 2003 and 2005, fertilizers obtained following the ecosan approach were tested on eleven different crops. The results, which are presented in Table 3, demonstrated that urine can replace urea as a fast-acting fertilizer while combined faeces and urine often gave as much as 30% more yield than the plots fertilized with equivalent mineral compounds (Dagerskog et al., 2008).

One trial carried out with sorghum in Ghana confirmed that the efficiency of urine as a fertilizer was at least comparable to that of the mineral ones. In this experiment the nutrient content of urine was determined and then enriched with phosphate, potassium and urea to provide the same amount of fertilizer as the commercial ones (Germer et al., 2008a). Other experiment conducted in the same country but using maize as an experimental crop demonstrated a fivefold increase in yield and corroborated that no significant difference exists between the use of urine or other nutrient treatments, suggesting that urine can be used to substitute mineral fertilizers without any unfavourable effect on the yield (Geller et al., 2008).

Table 3: Urine compared to mineral compounds and urea as a source of nitrogen, adapted from Dagerskog et al. (2008)

Plant		Aubergine	Tomato	Lettuce	Chou	Maize	Ground nuts	Manioc	Cotton
Country		Burkina		Togo		Benin		Côte d'Ivoire	
Reference plot		2.8	2.1	6.8	19.1	2.4	0.44	45	0.18
NPK+Urea	Harvest: Ton/ha	17.1	5.8	13.3	31.0	3.5	0.78	60	0.38
PK + Urine		16.0	5.2	15.7	32.0	3.6	0.56	60	0.35

Morgan provided in 2003 one of the most detailed and impressive results of using urine and humus derived from toilets following the ecosan approach. His results have clearly shown that the application of urine and humus as a fertilizer have a positive relation with the increase in crop yield.

Even if in plants such as lettuce or spinach the resulting yield increase was up to 6 times the one of the control, it was not as notable as the results for maize where a thirty-fivefold increase in production compared with the control was achieved.

2.3 Fertilizers

2.3.1 Overview

In order to grow, plants require water, light and nutrients. Some of these nutrients are non-mineral elements, such as carbon (C), hydrogen (H) and oxygen (O), and are taken up by a plant in larger quantities mainly from the atmosphere, as carbon dioxide (CO_2) and from the soil as water (H_2O). The rest of elements required for plant growth are mostly mineral and are divided into macronutrients and micronutrients. Plants usually take one hundred times more macronutrients than micronutrients. The elements classified as macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg) (Jönsson, 2004). From these macronutrients, N, P and K have to be applied in large quantities while S, K and Mg are required in smaller amounts. All these macronutrients are fundamental for many plant constituents, such as proteins, nucleic acids and chlorophyll and are also indispensable for diverse processes such as enzyme action and energy transfer (Isherwood, 1998).

The use of nitrogen is normally higher than the sum of other macro- and micronutrients together. This nutrient is taken from the soil in ionic form of nitrate (NO_3^-) and ammonium (NH_4^+). Nitrogen is mainly used for the formation of proteins in the plant. Phosphate is also taken up in the form of ions (HPO_4^{2-} and $H_2PO_4^-$) and is necessary for the cell division of the plants. Potassium is water-soluble and therefore plant-available. It is indispensable for plant growth, mainly during the first stages of this process. It is used by plants for the production of sugars, proteins, fats, etc. and also promotes the development of the roots. When one of any of these elements is present in insufficient quantity, it becomes the limiting factor that will hinder the growth of a plant and, as a result, it will not achieve its optimal growth or yield. If factors other than nutrients are limiting the development of the plant, such as light, pH or water, adding more fertilizers to the soil will not promote any further growth of it (Jönsson, 2004).

Micronutrients, which are taken up in smaller amounts, are boron, copper, iron, chloride, manganese, molybdenum and zinc. The scarcity of them may affect plant growth only under special circumstances. If human excreta is used as a fertilizer, their availability is guaranteed since it contains all the micronutrients needed by a plant (Jönsson, 2004).

As plants grow they take all macro- and micronutrients from the soil, and if they are not properly replaced the land will become deficient and infertile. To compensate this deficiency of nutrients, manure or fertilizers are used.

Mineral fertilizers are offered on the market in different forms and compositions. They can contain only one of the macronutrients or, when compounded, two or more of them. The notation of the composition can be deducted from the label. For example, the widely used compound "NPK 15-15-15" contains 150 grams of each of the labelled nutrients, in this case nitrogen (N), phosphorus (P) and potassium (K), per kilogram of fertilizer.

In 1984, the Food and Agriculture Organization of the United Nations (FAO) estimated that a reasonable assumption of the yield increase due to the use of fertilizer was that 1 kg of NPK fertilizer applied to the crop could produce around 10 kg of cereal grains. This statement was based on an extensive range of experiments carried out in a large number of countries.

2.3.2 Nitrogen-based fertilizers

All fertilizers require energy (mostly from fossil fuels) for their production, but the one that requires the most of it is nitrogen. It has been estimated that 5% of the worldwide energy consumption is used to produce fertilizers and 40% of this energy is used for producing nitrogen-based fertilizers, namely ammonia and urea. The energy requirements for producing these fertilizers are mainly met by natural gas, oil or coal, depending on the region in the world where they are produced (Isherwood, 1998). The main feedstock for ammonia/urea production, apart from air from where the nitrogen comes from, is energy and it accounts for almost 70% of the cost of producing these fertilizers (Gregory et al. 2006).

The largest consumers of nitrogen in the world are East and South Asia, North America and West Europe (FAO, 2008). It is projected that the demand for urea will increase dramatically in the USA because most new diesel-powered cars, trucks and buses manufactured from 2010 on will be requested to have a tank containing automotive grade urea installed, which will be injected into the exhaust system to abate the nitrogen oxide (NOx) from the engine's emissions. It has been estimated that the urea demand for transportation in the USA will be the equivalent of 210,000 tonnes of urea fertilizer, and that this amount will double by 2011 and keep increasing at the same rate that the older diesel-powered vehicles are substituted for new ones (Hargrove, 2008).

2.3.3 Potassium and phosphorous-based fertilizers

While the production of ammonia and urea is more dispersed in the world, the sources of potash and phosphate are limited to a few countries.

In the case of potassium-based fertilizers, the production is mostly concentrated in Canada, Russia, Belarus, Germany, and Israel (Gregory et al. 2006). The demand for this fertilizer is likely to increase 2.4% annually, which is equivalent to 3.6 million tones between 2007 and 2012. Almost 70% of this growth will take place in Asia and 26% in America (FAO, 2008).

In the case of phosphorous-based fertilizers, they are obtained from the phosphate rock, from which the largest commercially recoverable reserves are located in in the USA, China, Morocco/Western Sahara and in the countries adjacent to the Baltic Sea. Canada alone is the producer of 70% of the world's muriate of potash (Hargvrove, 2008). Due to the fact that the sources are limited for the phosphate fertilizers, their prices rise more abruptly than those of nitrogen- and potassium-based nutrients.

For the period 2007-2012, the estimated annual growth demand for phosphate is 2%, which is equivalent to 4.2 million tonnes in the entire period. As in the case of potassium-based fertilizers, considerable part of this growth, 71%, will take place in Asia and 18% in Latin America (FAO, 2008).

The current scale of phosphorus exploitation have raised alarms around the world. It is estimated that at 2% annual increase in rates of extraction the commercially viable reserves will last for one hundred years, being those of the USA the first to be depleted within the next 30 years (Rosemarin et al. 2007). Currently there are no known substitutes for this nutrient and the manufacture of phosphorus from alternative sources is impossible (Isherwood, 1998), however some of it can be recovered and reused from human, animal and organic waste.

If immediate actions to solve this problem are not implemented, the global economic development in the short term could be constrained by the availability of phosphorus and what could be worse, a huge alimentary problem might be left to the coming generations.

2.3.4 Fertilizer use in Africa

The following tables show the regional and sub-regional fertilizer consumption and Africa's fertilizer forecast for the period 2007-2012, according to the FAO.

Table 4: Regional and sub-regional fertilizer consumption 2007/8-2011/12 (FAO, 2008)

	N		P		K	
Regions and Subregions	Share of world consumption	Annual growth	Share of world consumption	Annual growth	Share of world consumption	Annual growth
World		1.4		2.0		2.4
Africa	3.4	2.9	2.5	1.0	1.6	2.0
North America	13.5	0.3	12.0	0.5	17.1	0.7
Latin America	6.3	2.4	13.0	2.8	17.5	2.9
West Asia	3.5	1.7	3.3	1.0	1.4	2.4
South Asia	19.6	2.2	20.5	3.5	10.9	4.2
East Asia	38.3	1.3	36.1	1.9	35.2	3.3
Central Europe	2.7	1.8	1.5	1.2	2.4	1.0
West Europe	8.4	-0.3	5.6	-0.7	9.5	0.0
E Europe and C Asia	3.0	2.4	.0	4.5	3.1	1.6
Oceania	1.4	4.9	3.5	1.7	1.3	2.1

From this information, it can be observed that, compared to the size of the African population which comprises 15% of the world's total, this continent accounts for less than 3% of the global fertilizer demand. Also the forecast from Table 5 indicates that it will continue satisfying all its potash needs with imports.

Table 5: Africa fertilizer forecast 2007/2008-2011/2012 (FAO, 2008)

	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012
			(thousand tonnes)		
N supply	4,441	5,316	5,605	5,929	7,454
Total demand	3,764	3,919	4,037	4,153	4,270
Surplus (deficit)	677	1,387	1,566	1,776	3,184
P supply	6,646	7,148	7,498	8,088	8,478
Total demand	1,368	1,383	1,393	1,404	1,414
Surplus (deficit)	5,278	5,765	6,105	6,684	7,064
K supply	0	0	0	0	0
Total demand	468	485	497	509	516
Surplus/deficit	-468	-485	-497	-509	-516

It is important to highlight that this data refers to the whole African continent, but a remarkable difference exists between the Northern and the sub-Saharan region and at the end that fertilizer consumption is restricted to 10 countries (out of 61) on the continent. The largest consumers of fertilizer are Egypt, Morocco and South Africa (FAO, 2008). As it can be observed in the following table, even if the total African consumption of the world fertilizer demand is too low, a great unbalance within the continent's demand exists.

Table 6: Share of fertilizer consumption within the African continent, adapted from (Gregory et al. 2006)

	Percentage of African population	Percentage of African fertilizer consumption
Northern Africa	20	45
Sub-Saharan Africa (without South Africa)	75	32
South Africa	5	23

The fertilizer production in SSA, mostly comprised of nitrogen and phosphate, reached its peak in 1992/93. Since then it has suffered a steady decline due to closures of ammonia and urea plants in Nigeria and declining productions in Tanzania, Zambia, and Zimbabwe. Between the period of 1990-2003, the total NPK production in SSA declined by more than 60%. In addition, the only reserves of potash in this region are located in Congo, and they are no longer commercially attractive (Gregory et al. 2006).

Apart from this decline in production, most SSA countries are also affected by higher costs due to inefficient supply chains, in the case of landlocked countries, the farmers end up paying extremely high prices for fertilizers, which strongly contributes to the constraint of the fertilizer use in most of SSA territory.

Gregory et al. estimated that in 2006 one tonne of urea had a Cost Insurance and Freight[1] (CIF) of US$160 in a port of the East Coast of the USA and of US$165 in the port of Lagos, Nigeria. After adding port charges, tariffs, handling, storage, interest on loans, insurance and transport to the final destination, 800 km for USA and 500 km for Nigeria, the urea reached the farmers at a cost of US$226 in USA and at US$336 in Nigeria. This means that the costs added through all the supply chain in the USA are equivalent to 30% of the final price and to 70% in the case of Nigeria.

1 Shipper/trader pays the cost of shipment up to the ship, insurance cost of cargo and freight cost up to destination port.

Transport distances, poor road infrastructure and even lack of competition in the transportation sector often increases the handling costs significantly. Also the variability of international prices and the imbalance caused by the constant devaluation of African currencies contributes considerably to this fact (Gregory et al. 2006).

2.4 General information of Ghana

Ghana is an English-speaking country located in West Africa and surrounded by Côte d'Ivoire to the west, Burkina Faso to the north, Togo to the east and the Gulf of Guinea to the south. It has an area of 238,533 km^2 and a population of 18,912,079 (Ghana, 2005). The country is divided in 10 administrative regions as shown in the following figure.

Figure 7: Administrative regions of Ghana[2]

The population of Ghana has grown considerably since the 1920s. In the last three decades there has been a steady increase in the number of urban centres in the country. In the year 2000, 43.8% of the population lived in urban areas, compared to 7.8% in 1921. The main urban centres are Accra and Kumasi, which in 2000 accounted for 34% of the total population of Ghana (Owusu, 2005).

2.4.1 The state of sanitation

The problem of wastewater disposal is serious in most of sub-Saharan countries. Currently thousands of tonnes of untreated faecal sludge are improperly disposed into inland waters, open

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urban and rural spaces and into the ocean (Steiner et al., 2002). As mentioned before, in West and Central Africa, the percentage of untreated wastewater that is dumped into fresh water bodies or coastal waters is above 80%. Domestic sewage is the most important source of pollution identified by the UNEP, so it has strongly recommended to focus on actions which could contribute to the reduction of this source of contamination (UNEP, 2004).

Between 1990 and 2006, the fraction of the population with access to improved sanitation facilities in Ghana was increased by 60% and that of people practising open defecation was reduced by 25% (WHO/UNICEF, 2008). Improved sanitation facilities, such as flush toilet, covered pit latrine and VIP/KVIP[3], were the most used in Greater Accra, by 82.7% of dwellers, followed by Ashanti Region, where the city of Kumasi is located, with 65.6 %. The regions below the national average of 55% are Volta, Brong Ahafo, Northern, Upper West and Upper East (CWIQ, 2003).

The main problems regarding sanitation in Ghana are the deficient government financial support in this area and that the attention has gone from preventive to remedial approaches. The lack of funding, education and planning is responsible for the growing propagation of waterborne diseases, with children being the most affected part of the population. Also, the lack of law enforcement has led to the improper disposal of human waste generated in public toilets and to the use of drain water and untreated faecal sludge for irrigation and cultivation (United Nations Department of Economic and Social Affairs [UNDESA], 2004; Tettey-Lowor, 2008).

2.4.2 The agricultural context

Even though the agriculture is a very important part of the African economy, the added value to its products has barely evolved during the last decades. On a global scale, the added agricultural value has steadily increased by 0.4 % each year since the 1960s and the only developing region that has more than doubled this added value per capita is East Asia-Pacific, while at the same time Latin America and South Asia have seen a small increase and what is worse, SSA has seen a declining trend in the same period (FAO, 2008).

The price of most agricultural crops in the world is affected by the increase in the oil prices. On one hand it increases the cost of most inputs and on the other hand the increase in demand for feedstock suitable for biofuel production, such as maize, sugar, rapeseed, soybean and palm oil, alters all the agricultural market.

One practice that is taking advantage of the lack of infrastructure for supplying agricultural products

3 Kumasi ventilated improved pits

to the West African cities is the rapid spread of urban agriculture. In Ghana, the land under informal irrigation in the urban-rural interface exceeds the area under formal irrigation of the entire country. The main problem of this kind of informal irrigation is that a considerable part of it is carried out with wastewater, putting densely populated regions at risk of diseases transmitted through this practise. The main motivation for irrigating with wastewater comes from the fact that farmers involved in year-round irrigation can earn two times more than those involved in rain-fed irrigation (Drechsel et al. 2006).

Most of the problems that farmers face in Ghana are related with transporting of their products and also with the huge costs of production derived from the cost of energy. The high costs of fuel makes it difficult for them to commercialize their crops in the right markets and also to hire the machinery that might boost their crop production. The Ministry of Food and Agriculture in Ghana (MOFA) has set objectives to diversify the agricultural production into cash crops and value addition and is also trying to develop value chains for most of the important cash crops. In addition, an Agricultural Land Management Strategy will be implemented as a tool to address the unsustainable use of land for agricultural purposes (MOFA, 2009).

The agriculture in Ghana accounts for approximately 35% of its gross domestic product. The cultivation of cocoa alone contributes an average of 30% of total foreign exchange earnings each year and 12% of total government revenue (MOFA, 2009; FAO, 2005).

Despite the fact that approximately 70% of the population in rural areas of the country are involved in agricultural activities, Ghana still imports 40% of its food needs and even if 57% of the total territory is agricultural land area, only half is under cultivation and the total irrigated area accounts for 0.08% of it, equivalent to only 11,000 ha (FAO, 2005).

Ghana is divided into six agro-ecological zones, as shown in Figure 8. These are, from north to south: Sudan Savannah Zone, Guinea Savannah Zone, Transition Zone, Semi-deciduous Forest zone, Rain Forest Zone and the Coastal Savannah Zone. The vegetation of each zone is determined on the basis of their climate and soil conditions. The mean annual rainfall ranges from 800 mm in the Coastal Savannah to 2200 in the Rain Forest zone (FAO, 2005).

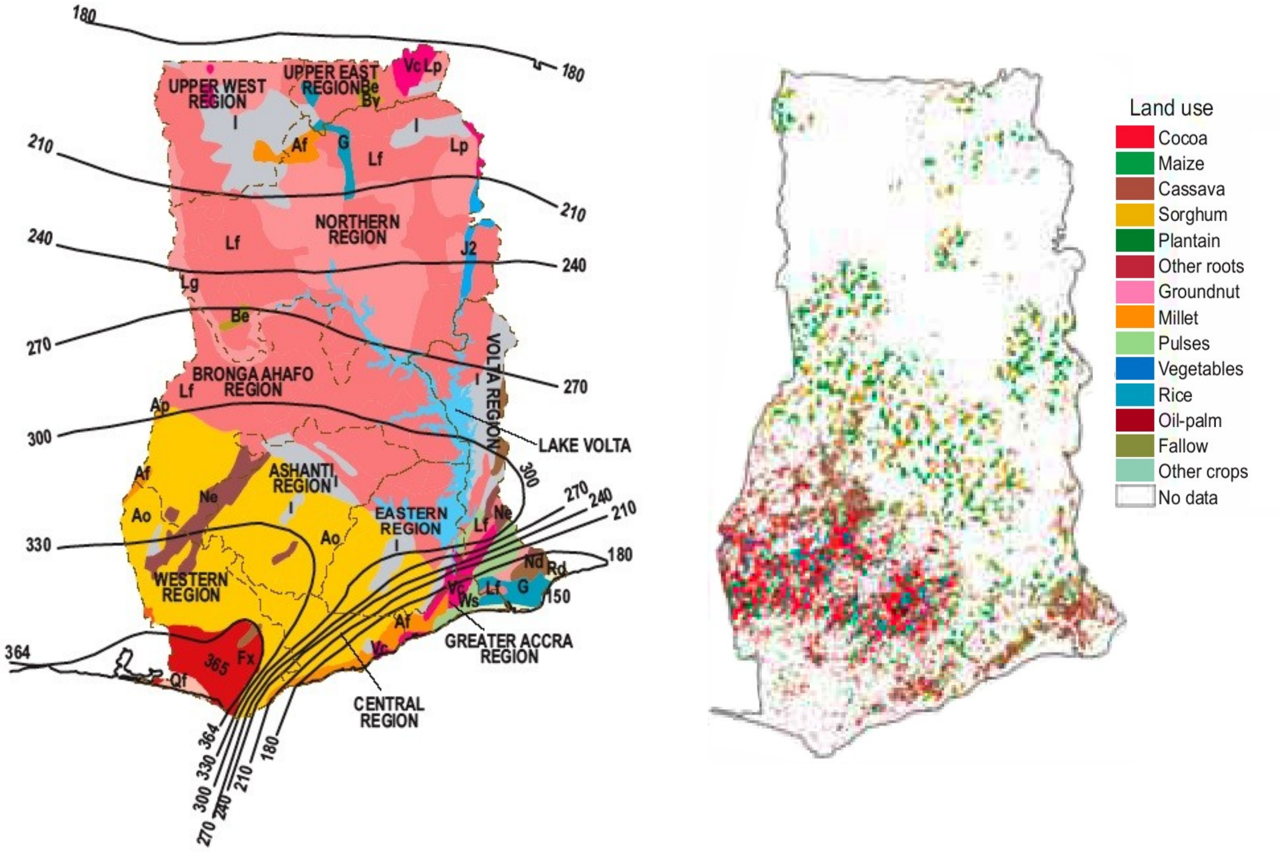

Figure 8: Agro-ecological zones and land use map of Ghana (FAO, 2005)

The principal agricultural crops produced in Ghana are shown in Table 7 and the development of the production of six of the industrial crops cultivated in the country are presented in Table 8.

Table 7: Crop groups (FAO, 2005)

Group	Crops
Cereals	Maize, millet, sorghum, rice
Industrial crops	Cocoa, oil-palm, coffee, cotton, tobacco, sheanut, cola nut
Legumes	Cowpea, bambara nut, groundnut, soybean
Fruits	Papaya, avocado, mango, cashew, watermelon, plantain
Vegetables	Tomato, eggplant, onion, pepper, okra, cabbage, lettuce, carrot
Roots and tubers	Yam, cassava, cocoyam, sweet potato

Table 8: Production of industrial crops (thousands of tonnes) (FAO, 2005)

Year	Cocoa	Coffee	Seed Cotton	Tobacco	Oil-palm	Sheanut
1996/97	322	2.9	25	2	984	22
1997/98	409	8.4	34	2.4	956	35
1998/99	398	4	38	2.6	1022	17
1999/00	437	2	36	2.5	1032	31
2000/01	390	1.4	18	1.2	1066	20
2001/02	341	1.5	18	2.2	1102	27
2002/03	475	1.5	15	n.a.	1100	n.a.

2.4.3 Fertilizer use in Ghana

The soil of Ghana is generally rich in potassium, but poor in organic carbon, nitrogen and phosphorus. The country is a net importer of fertilizer, between 1997 and 2001 these imports increased by more than 40% and most of them were comprised of NPK 15-15-15 fertilizer compound and ammonium sulphate (FAO, 2005). The major importers of fertilizer in Ghana are private companies such as Dizengoff, Agrimat, Wienco and Chemico. Also, the Agricultural Development Bank imports these products to the country.

Regarding the distribution of fertilizer, their major users, such as palm oil, tobacco, rice and cotton plantations, receive them directly from the importers or through one of the registered wholesalers located in the main cities of Ghana. The rest of it reaches the end users through a network of rural shops located in the country's districts (FAO, 2005).

The low level of fertilizer use in Ghana has lead to a constant deterioration of the soils because more nutrients are removed than brought back to it. Since the 1970s, the fertilizer consumption has followed an erratic behaviour, mainly influenced by the intermittent application of governmental subsidies and also to the swings of the economy that are affected by the constant devaluation of the local currency (FAO, 2005).

Currently, the government of Ghana has made GH¢37 million[4] available for subsidies in 2009 after fertilizer prices more than doubled between the years 2007-2009. In middle of the year 2009, the price of 50 kg NPK 15-15-15 was GH¢45 while at the end of 2008 it was GH¢26.

The subsidies are estimated to help finance 80,000 tonnes of fertilizer, which are available for

4 Exchange rate as of September 2009, GH¢ 2.0 = € 1.0 = US$ 1.5

small-scale food crop producers. The government estimated a loss of GH¢62.5 million in national production of maize if fertilizers were not used due to their high costs and at the end this quantity of cereal would need to be covered by imports (Ghana News Agency [GNA], 2009). Data collected from different regions in Ghana demonstrates that the application of subsidies has had very positive effects on the economy of the farmers by increasing their crops yields up to 50% after the application of fertilizer that would have not been applied if not subsidized (Public Agenda Accra [PAA], 2009).

2.4.4 Use of non-mineral fertilizers in Ghana

Danso et al. carried out a study in 2006 to measure the willingness of the urban farmers to pay for fertilizer derived from human excreta in various cities of Ghana. This study revealed that the demand for this kind of compost is marginal and most of the times limited to the cost of transporting it to the farms. The study concluded that such operations could only be carried out through a private-public partnership where subsidies would be required to increase the agricultural use of treated human waste.

This study also revealed that the most used organic fertilizers are, depending on the regional availability, poultry manure, cattle dung and even untreated human excreta. The use of poultry manure has many advantages with regard to the rest of the options, mainly because of its relatively higher availability, low price, efficiency and good long term effects in the quality of the soil. This manure is abundant in the peri-urban area of Kumasi and as such it is the most used in that region. In the case of Accra, this product is also abundant but there is more competition in getting it than in Kumasi.

In Tamale, the third largest city of Ghana, the use of septic sludge, altogether with cattle dung and fertilizers is practised (Danso et al. 2006). Cofie et al. (2007b) reported that farmers in the area pay to the septic truck drivers for dumping their load on the crop fields. On the other hand, Tettey-Lowor (2008) reported the concern of farmers who produce for export markets about the safety of using hygienized excreta as a fertilizer due to hygienic concerns and also about the irreversible damage to their reputation that might be caused by any publication in the media about farmers using human waste for fertilizing food addressed to foreign markets.

2.4.5 Situation in Accra

The city of Accra is located in the Greater Accra Region, which has an extension of 3,245 km^2. Even though the land surface represents less than 2% of the total area of Ghana, it concentrates 12% of the habitants of the country (2,167,675 in 2008). The city has an annual population growth rate of 4.4%, converting it into one of the most populated and fast-growing metropolis of Africa. Accra concentrates the major part of the industrial, manufacturing and commercial activities in the country. Also, the city houses most of the cultural, educational and political administrative functions, which has lead to an ever increasing migration of persons from inside and outside of the country (Ghana, 2005).

The Greater Accra Region is divided into five districts: Accra Metropolitan Area, Tema Municipal Area, Ga East District, Ga West District, Dangme East District and Dangme West District.

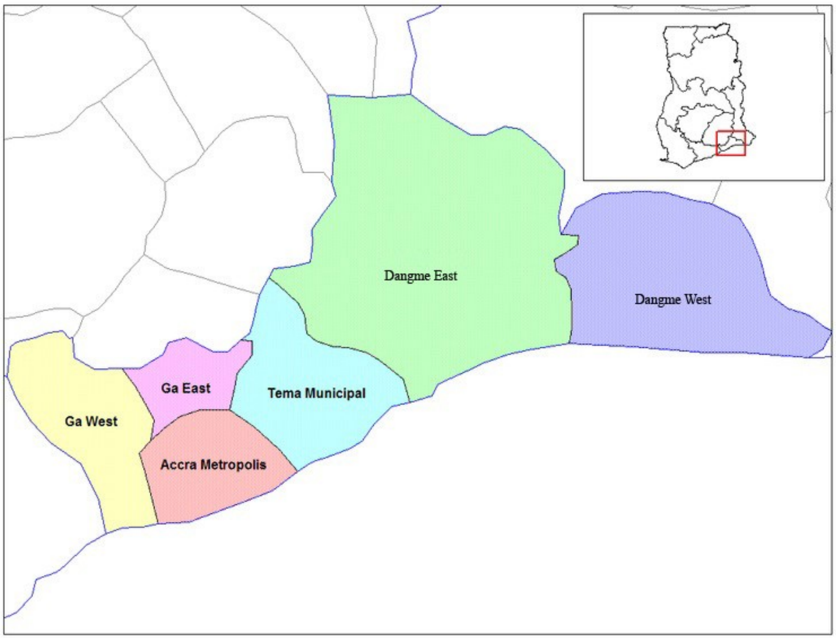

Figure 9: Greater Accra Region[5]

The Akan is the major ethnicity, followed by the Ga-Dangme and the Ewe. Christians are the largest religious group (83%). Other religious beliefs include Muslims, followers of traditional religions and people not practising any at all. Compared with the rest of Ghana, the GDP per capita in the capital city is well-off. In 2008, people in Accra had a GDP of US$915, which is relatively higher than Ghana's GDP of US$350 (Ghana Districts [GD], 2009).

Regarding sanitation conditions, almost 60% of the population in Accra lives in low-income areas with a wide range of environmental and sanitation problems. One third of the population uses public

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toilet facilities, most of which are located close to markets and bus stations, and they are charged GH¢0.20 for using the toilet or GH¢0.05 for the urinals. Other sanitation facilities used are KVIP (11.7%) and water closets in the houses (22%). Twenty years ago a plan to phase out the use of bucket or pan toilets was introduced in the city, but the lack of law enforcement caused that these sanitation means are still used by 12.7% of households in Accra. This situation also brings along other sorts of sanitation issues due to inefficient collection and disposal of excreta collected in these depositories (GD, 2009).

In Accra, the Waste Management Department is responsible for collecting and disposing of the waste generated in the metropolitan area, but it is currently capable of collecting only 60% of it. The rest is disposed of in open spaces, water bodies and surface drains. Waste management in the city has been problematic already for a long time. One of the worst cases of severe pollution is exemplified by the Korle Lagoon, which is the outlet for most of the untreated domestic and industrial waste generated in Accra and further on into the sea. This lagoon is severely polluted and has become one of the most contaminated water bodies on the planet. Apart from the irreversible ecological damage that has been caused on it, one of the risks posed by the high pollution of this lagoon is the constant overflow, which causes dangerous floods in some parts of the city (Owusu-Boadi, 2002).

2.4.6 Situation in Kade

Kade is one of the semi-urban settlements of the Kwaebibirem District, which is located in the moist semi-deciduous vegetation zone of the Eastern Region of Ghana. The district has an extension of 1230 km^2, its population was estimated to be 196,992 in 2005 with an annual growth rate of 1.9%. The district is predominantly rural as 63% of the population resides in the rural countryside. The semi-urban settlements are Kade, Akwatia, Asuom, Boadua, Abaam and Takrowase. Since the human settlements in Kwaebibirem are separated from each other by no more than 8 km, there is a strong economic and social interaction between them (Ghana, 2005; GD, 2009).

As is the case of the Greater Accra Region, Akan is the major ethnicity, followed by the Ga-Dangme and the Ewes. Christians and Muslims are the two major religious groups with 91% and 7% of the population practising them, respectively (GD, 2009).

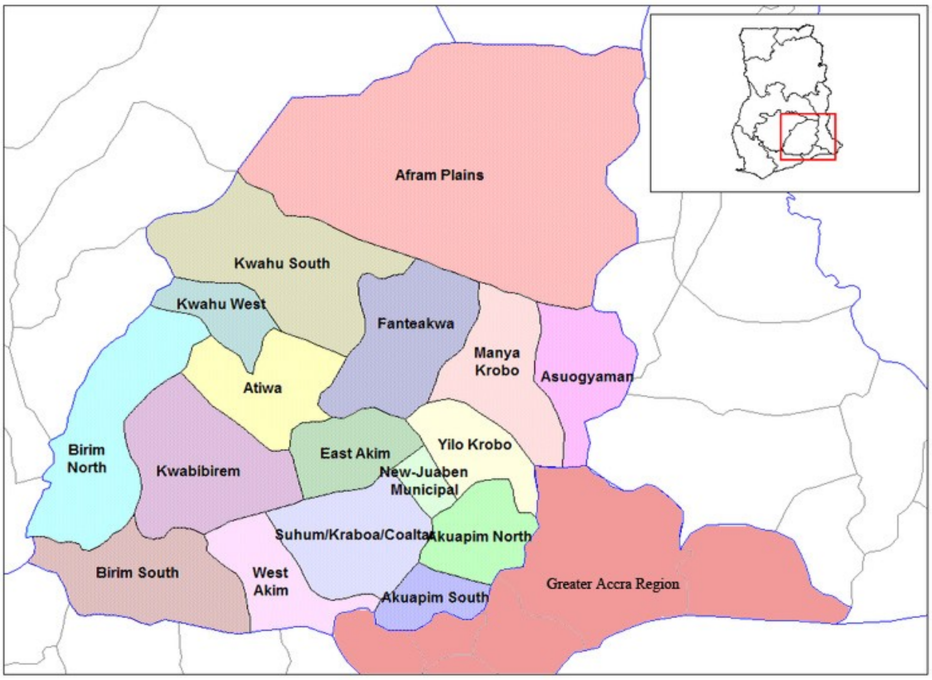

Figure 10: Map of Eastern Region[6]

Regarding the state of sanitation, most settlements in the district lack improved toilet facilities. The most used ones are pit latrines (40%), public toilets (29%) and KVIP (7%). A small fraction of the population, 3%, still practises open defecation. According to a survey conducted within all the local councils in the district, the construction of public toilets was identified as one of the major communities' needs that require immediate attention (GD, 2009). The fees charged in public toilets in the district are GH¢0.10, either for the use of toilet or urinal.

The agriculture accounts for 77% of the economic activity in Kwaebibirem District, followed by 11% of industrial activities and the rest distributed between commerce and services. The district has abundant mineral, forest and agricultural resources. It produces diamonds, gold and various types of timber. The cash crops include cocoa, cola, oil palm and citrus. The food crops grown are plantain, cocoyam, cassava and a wide variety of cereals and vegetables (GD, 2009).

The district houses the largest oil palm mill in West Africa, operated by the Ghana Oil Palm Plantation Development Company (GOPDC). In addition, there are numerous small-scale oil mills spread along the district and more than 40,000 ha of land are cultivated with oil palm from which the GOPDC owns about 11,000 ha.

Even though the agricultural resources are abundant, farmers in the region depend on labour intensive and subsistence agriculture. The erosion of the soil is remarkable in various urban and

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rural settlements and the need of intensive tree planting has been proposed to counter back this situation. The deforestation has also driven to excessive evaporation of smaller rivers which has lead to water shortages during dry seasons. In addition, the scarce application of fertilizers, the low level of modern agricultural technology and the over dependence on the weather leads to generally low agricultural productions of small-scale farmers in the district (GD, 2009).

2.5 Palm oil and biodiesel

2.5.1 Palm oil

Palm oil is extracted from the fruits produced by the oil palm tree. This oil is employed in a wide variety of industries, from cosmetics to cooking and from automotive engine fluids to tooth paste. About 90% of the palm oil is used in the food industry and the rest is processed for production of oleo-chemicals (Demirbas, 2008). This crop produces two oils, the palm oil and the palm kernel oil, both with different characteristics, which determine their applications in the industry.

Figure 11: Oil palms in Kade

The oil palm is grown in many agricultural regions of Africa. The ideal climate for its cultivation prevails in regions with tropical climate and a rainfall of 1600 mm/yr or more, distributed evenly throughout the year. A mean maximum temperature of about 29-33ºC and a mean minimum of 22-24ºC also belong to the most favourable conditions. This crop grows well in deep well-structured and drained soils, which are found in a wide range of tropical regions.

Even if the origins of oil palm are in the tropical rain forest in Africa, the high potential productivity of this crop has encouraged its extensive cultivation in many developing countries. Today, nearly 80% of the palm oil in the world is produced in Southeast Asia, particularly in Malaysia and

Indonesia.

The oil palm is one of the most productive and less destructive alternative crops for degraded forests and deforested areas in the tropics. This tree has the highest yield between the most used oil crops in the world (Tailliez et al., 2005; Muttert, 1998). The energy balance of the oil palm (Figure 12) has shown to be one of the highest among other crops that produce oil (input:output = 1:9.5) and this makes it one of the best choices for renewable energies in the future (Muttert, 1997).

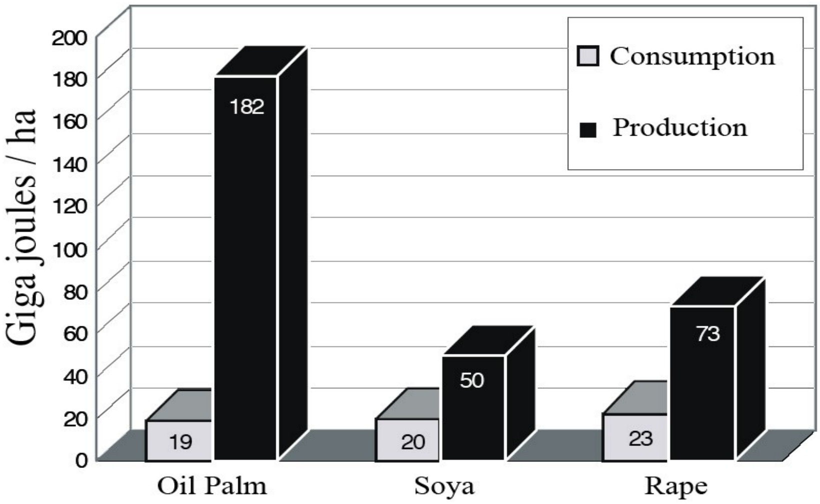

Figure 12: Energy balance of the oil palm, soya and rape oils (Muttert, 1997)

The palm oil produces its fruit in bunches (known as fresh fruit bunches, FFB), which weight varies from 20 to 30 kg. The following diagram illustrates the FFBs and the structure of the fruit:

Figure 13: Fresh fruit bunches and palm fruit structure

The mesocarp and the kernel contain the palm and kernel oils, respectively. Under ideal conditions, high-yielding varieties of oil palm can produce up to 20 tonnes of FFBs a year. Since generally 25% of the FFB weight is oil, a yield of 5 tonnes of oil/ha can be obtained. For achieving such a good yield, favourable climate conditions, appropriate fertilization and good management of the plantations are necessary.

The palm and kernel oil extraction process can be summarized as follows: after the reception of FFB they are sterilized with steam, then the fruits are separated from the bunches and are mashed and pressed to extract the crude palm oil. For kernel oil, the kernels are crushed into small particles, then they are heated to finally extract the oil using an oilseed expeller or a solvent. Palm and kernel oil require further treatments depending on its final use.

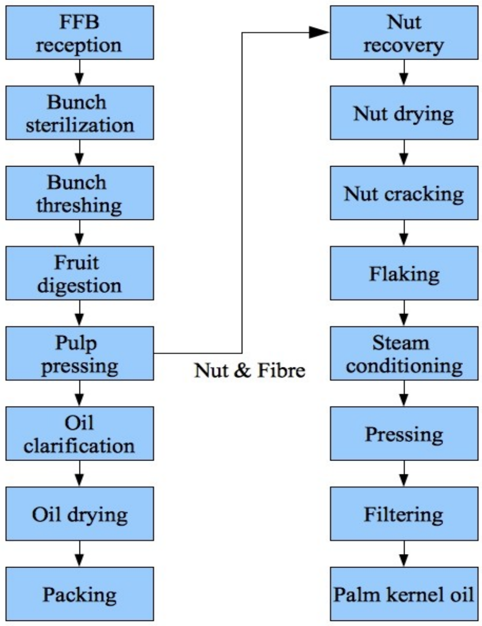

Figure 14: Palm and kernel oil extraction process

In Ghana, oil palm is the second most important industrial crop after cocoa. In 2003, the country had 304,000 hectares of land cultivated with this crop (representing 20% of the total area for industrial crops), of which approximately 35,000 hectares were cultivated by four main private companies and the rest by more than 600,000 small-scale farmers (Adamtey, 2005; FAO, 2005). The Eastern, Central, Western and Volta regions concentrate most of the oil palm cultivations in Ghana.

Table 9: Oil palm cultivated area in Ghana (FAO, 2005)

Year	Area planted (thousand ha)
1994	256
1995	262
1996	267
1997	273
1998	279
1999	285

Nearly all the palm oil mills in the country are small-scale or artisanal ones. These plants carry out their processes with very simple equipment, most of the time human-powered, and they have processing capacities that vary from few hundred kilograms up to 8 tonnes of FFB a day. The large-scale plants perform all the stages of the process by means of mechanical systems and are able to handle between 3-60 tonnes of FFB per hour (Poku, 2002).

The extraction capacity of small-scale plants is at most 15% of the FFB weight, while in the larger-scale ones 24% can be achieved for oil palm and 3% in the case of kernel oil. Usually, small-scale mills do not have the capability of processing palm kernel oil, and then these nuts are either thrown away or sold to palm kernel processors.

Most of the solid wastes that result from oil extraction can be used at some stages of the process to produce energy. In small-scale mills, fibre is used as fuel for heating FFB and in the case of large-scale ones fibre and shell are used to fuel steam generators to produce electricity for the mill (Poku, 2002).

For the fertilization of oil palm, nitrogen is a very important nutrient. It is required for the rapid growth of young seedlings in the field. The preferred source of nitrogen in this crop is ammonium sulphate, but urea and ammonium nitrate are also used. The high costs of these fertilizers have lead to the suboptimal or no application of them in the country (Adamtey, 2005). Even for big companies, which do not receive the governmental subsidy, the cost of fertilizing has sky rocketed since 2008, resulting in the suspension of the use of fertilizers until the prices go down again or the yield of the fields decreases significantly. Nowadays, there is an urgent need for developing alternative cost-effective and sustainable nitrogen management systems for oil palm plantations in Ghana (Adamtey, 2005).

Oil palm requires large quantities of potassium and, since this nutrient is contained in stalks, fibres and shells, it is removed at harvest. Apart from being part of the palm structure, potassium has a direct effect on the functioning of the chlorophyll molecule in photosynthesis. Also, this nutrient plays an important role in the tolerance of oil palm to drought and the effects of diseases caused by fungal pathogens (Adamtey, 2005). Potassium represents a big share in fertilizer consumption in Ghana, which is attributed to its intensive use in the palm oil industry (FAO, 2005).

2.5.2 Biodiesel

The term biofuel refers to liquid or gaseous fuels mainly obtained from biomass. At the global level, they are mainly used to power vehicles, houses or to produce heat for cooking. This kind of fuels is important because of having the potential to replace petroleum-based combustibles. Biofuels are mainly bioalcohols, biodiesel, bioethers and biogas.

Biodiesel is a renewable fuel for diesel engines derived from natural oils. From more than 350 oil crops that have been studied for its potential use as biodiesel, only soy bean, palm, cotton seed, peanut, sunflower, rapeseed and safflower oils are considered as potential alternative fuels for diesel engines (Demirbas, 2008). Even if raw vegetable oils could be used as diesel fuels, disadvantages such as poor fuel atomization, weak cold engine start-up, gum and other deposit formation make it difficult to feed an engine with them. That is why these vegetable oils have to go through a series of chemical reactions to permit its use in diesel engines.

Table 10: Raw materials used for producing biodiesel (Demirbas, 2008)

Country/Region	Raw material
USA	Soybean
Malaysia and Indonesia	Palm oil
Europe	Rapeseed
India and Southeast Asia	Jatropha

The main process to convert raw vegetable oil into biodiesel is called transesterification, also known as alcoholysis, and it consists of the reaction of oil with an alcohol, mainly methanol or anhydrous ethanol, together with a catalyst, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), in order to separate fatty acid methyl esters (which are the basis for biodiesel) and glycerol (Jitputti et al., 2006).

Biodiesel produced from various vegetable oils has similar characteristics to petroleum-based diesel, including viscosity, boiling temperature, cetane number, etc. The heat of combustion, which measures the amount of heat released when a fuel is burned in the presence of oxygen, is slightly lower in biodiesel than in petrodiesel. On average, there is a 10% reduction in power when using biodiesel, i.e. it takes 11 litres of biodiesel to equal the energy content of 10 litres of standard diesel (Demirbas, 2008). On the other hand, biodiesel's technical advantages include the fact that its use prolongs the engine life and reduces the need of maintenance (a biodiesel blend of just 1% could increase fuel lubricity by as much as 65%), it is safer to handle, less toxic and reduces the exhaust gas emissions considerably, although, as can be observed in Table 11, it may raise others (United States Environmental Protection Agency [USEPA], 2002).

Table 11: Emission impacts of 20% vol. biodiesel for soybean-based biodiesel added to an average base fuel (USEPA, 2002)

	Percentage change in emissions
Nitrogen oxides	+2.0%
Particulate matter	-10.1%
Hydrocarbon	-21.1%
Carbon monoxide	-11.0%

Biodiesel is slightly heavier than standard diesel (870 kg/m^3 for biodiesel and 840 kg/m^3 for petroleum-based diesel), but despite this fact they can be mixed to form a wide range of different blends, which are referred with the notation BXX, where the XX indicates the amount of biodiesel in the mixture. For example B20, the most commonly used blend, is 20% biodiesel and 80% petrodiesel.

B100 blends can be used in any diesel engine no older than 10 years. The only modification needed for older engines is the replacement of all natural rubber seals with synthetic ones, due to the solvent characteristics of biodiesel.

Biodiesel has the potential of reducing the greenhouse effect mainly through absorption of the CO_2 from the atmosphere in order to produce biomass that will be converted into fuel. When this fuel is burnt, it simply returns the CO_2 that was already in the atmosphere, and if only this fact is taken into account, biodiesel could be considered as carbon-neutral fuel. On the other hand, petroleum-based diesel is made from fossilized plant material that absorbed CO_2 from the atmosphere millions of years ago, and when burnt, excess CO_2 is released altering the delicate balance of gases in the atmosphere.

Even if biofuels offer many advantages, such as reduction in greenhouse gas emissions, regional development or security in energy supply, the complete cycle of production must be evaluated to include their environmental, economic and social impacts. Nowadays, no biofuel is carbon-neutral and the CO_2 emissions released by fossil fuels used during the agricultural (including the production of fertilizers), manufacturing and distribution processes involved in the biofuel supply chain, could sometimes exceed those of fossil-based fuels (Cockerhill et al. 2008).

Currently, biofuel costs 1.5 to 3 times more than petrodiesel. Whether biodiesel is a feasible alternative to fossil fuel or not, depends on variables such as the feedstock used, market conditions and the consideration of the positive externalities, like environmental impact, trade balances, etc. that are not always reflected in the price mechanisms (Demirbas, 2008).

Table 12: Availability of modern transportation fuels (Demirbas, 2008)

Fuel type	Availability	
	Current	Future
Gasoline	Excellent	Moderate-poor
Biodiesel	Moderate	Excellent
Compressed natural gas	Excellent	Moderate
Hydrogen fuel cell	Poor	Excellent

Today, in a growing number of regions, locally abundant vegetable oils are transformed into biodiesel to operate multiple devices and obtain energy to satisfy basic needs. A small diesel engine (10 horsepower) is often used to drive a press, generate electricity, pump water, charge batteries, power a mill, compress air, etc. In SSA, the most widely available crop for producing biofuel is oil palm. In several countries successful projects are being carried out to demonstrate the use of this oil in small-scale biodiesel plants. The Common Fund for Commodities, an intergovernmental financial institution based in the Netherlands, has implemented small-scale palm oil projects in Cameroon, Benin, Cote d'Ivoire, Ghana, and Nigeria (UNDESA, 2007).

Much concern exists in the world about the use of food crops as feedstock for biofuel. But it does not make sense to condemn the production of this source of energy in developing countries in which considerable amount of vegetable oils are exported at commodity prices (e.g. GH¢0.82/litre of palm oil[7]) and then, diesel is imported to be sold at prices that depend on world market conditions. As it will be detailed in Section 3.5, one litre of biodiesel could be produced in Ghana for GH¢0.85, while petrodiesel had an average price of GH¢1.27/litre[8] during 2009, and reached GH¢2.5/litre during the oil prices peak in middle 2008.

Even tough current palm oil yields in Ghana are much below its well-managed yields, the country

7 Price provided by GOPDC, on August, 2009

8 Average price of diesel between September 2008 and September 2009, based on records from the Agricultural Research Station of the University of Ghana in Kade.

exports significant amounts of this product to be processed in other countries. Nowadays, there is no serious project trying to refine palm oil for biodiesel, which is a higher value commodity that could help to improve the country's trade balance or use it to satisfy its own energy needs. A study from the University of Wisconsin has identified Ghana as the only African country with high probabilities of becoming a leading producer of biodiesel, mainly due to its geographical location, relative safety, stability and lack of debt, among other economic factors (Johnston et al. 2007).

In 2005 the government of Ghana set up a committee to define strategic goals on the energy agenda. After completing this study, the committee recommended the government to accelerate the development of the renewable fuels industry. As a result, in 2006, the Strategic National Energy Plan was released and one of the main objectives of this plan is to boost the biofuel industry and achieve a 10% penetration of liquid fuels by renewable and alternative fuel complementation by 2015, expanding to 20% by 2020 (Ghana Energy Commission [GEC], 2006).

Existing biofuels projects in Ghana, mainly focused on the production of biodiesel using jatropha as feedstock, have proven to be effective to stop, or even reverse, migration of farmers from areas that were abandoned due to the lack of opportunities. Poverty and absence of paid employment forced young people to migrate in search for jobs, but as a result of the investments made in the jatropha-based biofuel sector, some of these people had returned home with the hope of employment (Ghana Business News [GBN], 2009).

2.6 Summary

After considering all the facts presented in the first section of this work, it can be concluded that the lack of appropriated means for disposing of human excreta in developing countries has lead to massive releases of untreated wastewater that severely pollute open spaces, rivers, lakes and oceans. This situation has two undesirable effects: the water bodies become polluted due to the excess of nutrients and the soil is rapidly depleted of them. In addition, the need for economically affordable fertilizers exists in most of the developing countries in the world. Many constraints have made fertilizer use unprofitable for subsistence farmers and this has also contributed to an accelerated depletion of nutrients in the soils.

In trials carried out in multiple countries, the ecosan approach has demonstrated to be a proper way for managing waste and reusing the nutrients contained in it. Moreover, it is a simple technology that can be implemented at low cost in almost any region of the world.

After analysing the state of sanitation and agriculture in Ghana, it can be concluded that it offers a good field for studying the implementation of the ecosan approach in this country. Also, Ghana possess a well established palm oil industry, which is currently producing under its optimal level mainly due to the lack of use of fertilizers. Also, palm oil has the advantage of being used to produce a widely used product, such as fuel, which fits well to start using human excreta for fertilizing crops without the risk of social rejection of this product.

The following chapter details a supply chain that is aimed to support the implementation of the ecosan approach in Accra and Kade, without the need of complex technologies, huge investments or governmental subsidies. It also aspires to overcome the challenges that previous studies have found when trying to implement this sanitation concept on a large scale in urban and rural areas, mainly those concerned with the high transportation and storage costs derived from the low value-to-volume ratio of urine.

3 Supply chain for ecological sanitation

In this chapter a supply chain for the successful implementation of sustainable sanitation is proposed for the cases of Accra and the semi-urban settlement of Kade, in the Kwaebibirem District.

For the purpose of this research, only the collection, transport, storage and further use of urine as a fertilizer is going to be detailed. The reason is that urine represents almost 90% of the volume and contains most of nutrients in human excreta. Moreover, in UDDTs faeces are left to dry and during this process their original volume is reduced up to 80%, which makes it easier to handle them following the same processes employed for other organic solid wastes.

In the first section, the monetary value of the nutrients contained in urine is to be determined in order to define its value-to-weight ratio. The definition of this relation is important to plan the logistics strategy for urine as a product with low value-to-weight ratio often incur in relatively high transport and storage costs. In the next parts, sanitation and storage facilities, as well as transportation means and requirements for a small-scale biodiesel plant are proposed.

Next, the supply chain for ecological sanitation is proposed for the specific cases of Accra and Kade and finally the stakeholder's analysis is carried out to identify how the individuals or groups that are involved in the proposed supply chain might be affected by its implementation.

3.1 Value-to-weight ratio of urine

To estimate the value of the nutrients contained in urine a method proposed by Drechsel et al. (1999) is followed. In this analysis, the cost-price ratio between macronutrients is determined based on the world prices of their raw materials and the percentage content of each nutrient in them. Based on these price ratios, the nutrient content of a commercial compound in nitrogen equivalents is determined (Table 13). Using this results, one kilogram of NPK 15-15-15, which has a cost[9] of GH¢0.9/kg has an equivalent nitrogen content of 1.11 kg, which led to the price of each nutrient as presented in Table 14.

9 Price as of September 2009: GH¢45 for a 50 kg sack of NPK 15-15-15, in Agrimat Ltd, Legon-Madina Highway, Accra

Table 13: World market prices of fertilizer raw materials

Raw material	N (NH_3)	P (H_3PO_4)	K (KCl)
World price[10] (US$/mt)	260	660	550
Nutrient in raw material (%)	77	53	60
Price of each tonne of nutrient (US$)	338	1245	917
Ratio (Nitrogen=1)	1	3.69	2.71
NPK 15-15-15 standardized to nitrogen (kg)	0.15 x 1 = 0.15	0.15 x 3.69 = 0.553	0.15 x 2.71= 0.407

Table 14: Average nutrient costs in the Ghanaian market

Nutrient	GH¢/kg
Nitrogen	0.8
Phosphorus	2.9
Potassium	2.2

Using the information provided by Germer (2008b) and Cofie et al. (2007a) the nutrient content in human excreta (estimated for the Ghanaian population) is presented in the following table:

Table 15: Nutrient content in urine and faeces (case of Ghana)

	Nitrogen	Phosphorous	Potassium
Urine (g/l)	5.9	0.7	2.7
Faeces (g/kg)	4.3	1.0	0.9

Finally, using the information from Tables 14 and 15 the value of the fertilizer content in urine and faeces can be calculated as follows:

Table 16: Market value of nutrients contained in urine and faeces (case of Ghana)

	Nitrogen	Phosphorous	Potassium	Total
Urine (GH¢/1000 litres)	4.78	2.05	5.94	12.77
Faeces (GH¢/tonne)	3.56	3.00	1.96	8.51

From these results, it can be observed that the maximum cost that might be incurred in the collection, transportation, storage and application in the field of human excreta should be at most

10 Prices as of September, 2009, obtained from suppliers in different countries

GH¢8.5/tonne for the case of faeces and GH¢12.7 per 1,000 litres, for urine. This is in order to be able to compete with the mineral fertilizers available in the Ghanaian market. Of course, these prices might be recalculated in case of significant changes in the price of commercial fertilizers.

3.2 Sanitation facilities

The proposed sanitation facilities consist of a UDDT block with six toilets (squatting pans), one urinal and one sink, as presented in Figures 15 and 16.

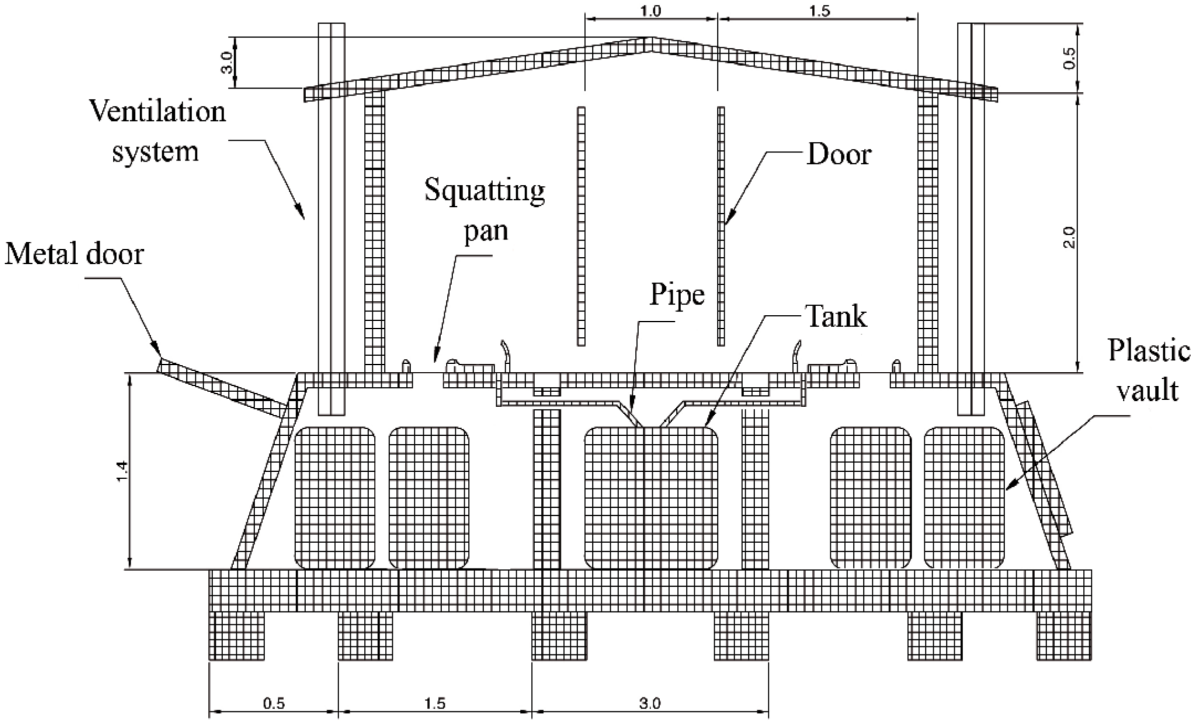

Figure 15: Transversal view of the proposed UDDT (measures in metres)

The squatting pans proposed are similar to the one presented in Figure 17. Drewko[11] reported in 2009 that a similar ceramic squatting pan produced in Ethiopia may cost €17 (GH¢34). For the proposed UDDT complex of this project, a cost of GH¢35 will be assumed.

11 Information gathered by Drewko through e-mail correspondence with Ethiopia

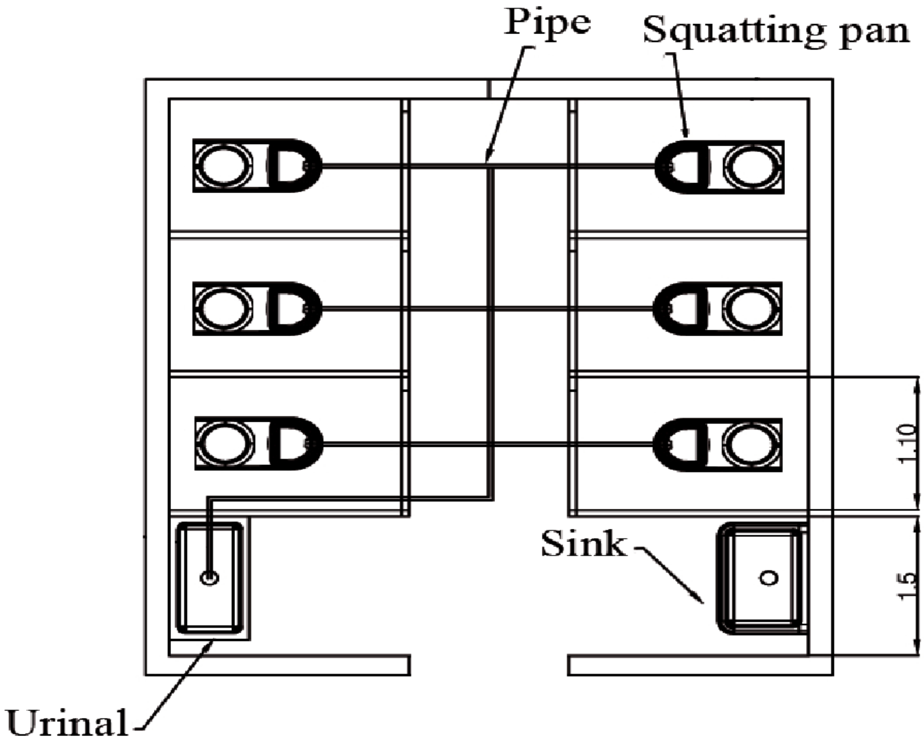

Figure 16: Aerial view of the proposed UDDT[12]

The hole in the squatting pan for faeces has a diameter of 30 cm. Faeces drop through it into a plastic vault placed in the basement, which is replaced by the adjacent one each time it gets full, to allow dehydration of the faeces. The metal doors are located at the sides of the complex to remove the plastic containers after the dehydration period and transport them to the composting facilities. The ventilation system helps to prevent the odour and can be equipped with an electric or wind-activated fan to improve this process.

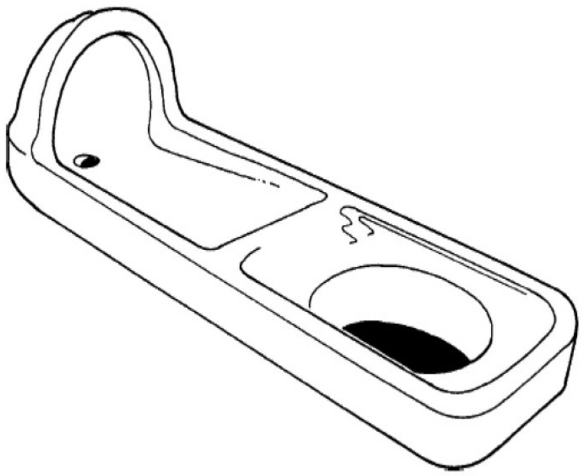
Figure 17: Squatting pan with urine diversion, made of porcelain (Esrey et al., 1998).

It is important to highlight the importance of adding ashes or sawdust to the faeces after each use, as

12 The connections for collecting the urine are shown in the Appendix A

mentioned in Section 2.2.3, this will help to reduce the odour and eliminate pathogens by elevating the pH. Also the drying inside the collection chambers contributes to the disinfection process (Boost et al. 1998). Figure 18 illustrates the proposed ecosan toilet complex.

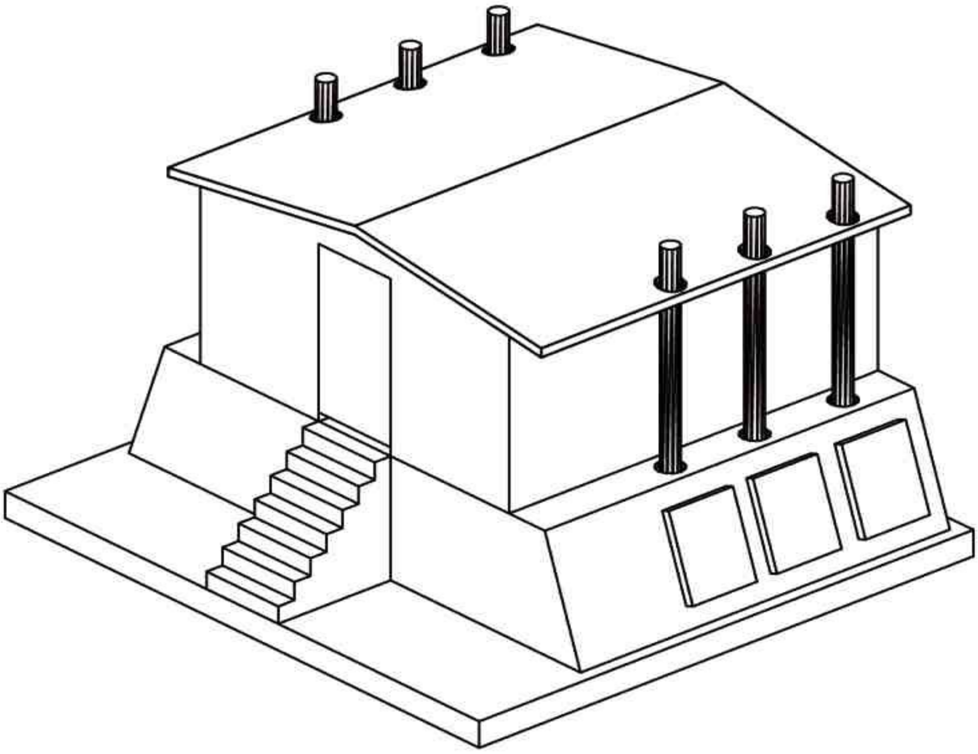

Figure 18: External view of the UDDT complex

This toilet is based on a complex built at the Valley View University (VVU) and is estimated that it can be used by 500 people. A break down of the building costs are shown in Table 17.

Table 17: Costs break down[13]

Item	Quantity	Unit	Cost (GH¢)
Roofing sheet	20		140
Roofing nails	1	box	10
Wire nails 3” x 4”	12	lbs	12
Timber boards 2 x 4 x 14	30	board	95
Timber boards 1 x 12 x 14	15	board	70
Cement	65	50 kg bag	780
Blocks 5”	900		900
Iron rods 1/2”	50		70

13 Quotation provided by Mr. Tete Mantey. Prices as of September, 2009.

Item	Quantity	Unit	Cost (GH¢)
Urinal	1		60
Toilet	6		210
Lavatory	2		90
Sand and gravel	4	trips	400
Oil paint	4	gallon	72
Emulsion paint	2	bucket	36
PVC pipe 4”			55
PVC pipe 1 1/4”			30
Taps			20
Plastic containers	12		600
Plastic tank (3,000 l)	1		500
Electricity work			50
Miscellaneous			350
Labour			900
		Total cost	**5,450**

It is worth to mention that the biodiesel plant proposed in Section 3.5 will have to dispose of a considerable quantity of metal and plastic drums (with 200 litres capacity), in which methanol is imported. By using them in the proposed toilet block, instead of buying new ones, the cost of construction will be reduced, i.e. the new UDDT complex described in Table 17 would cost approximately GH¢4,800.

Table 18: Estimated costs for other constructions[14]

	Using new plastic tanks (GH¢)	Using the drums disposed from the biodiesel plant (GH¢)
Upgrading an existing six-toilet complex to a UDT type	1,665	N.A.
Upgrading an existing six-toilet complex to a UDDT type	2,995	2,400
Upgrading an existing public urinal to collect urine in a 2,000 litres underground container	774	N.A.

14 Cost break downs for these constructions are detailed in Appendix B

3.3 Transportation

Previous works have proposed the use of a suction truck (Cofie et al, 2007b) or a pick up mounted with a tank (Tettey-Lowor, 2008) to start collecting urine generated in public toilets of Accra. But the main challenge presented with these means of transportation is their cost, approximately US$25,000 for the vacuum truck, or the fact that they can only be used for transporting urine.

The proposal of using a suction truck to collect urine can be discarded since urine is a liquid and these trucks are designed to collect faecal sludge, which is a thick fluid, thus requiring a specialized equipment. Taking this into account, the case of a heavy duty truck equipped with a water pump and mounted with one or various containers to sum up a capacity of 7,000 litres is going to be analysed.

Table 19: Specifications for the selected truck

Isuzu FRR	
Year	2003
Class	Class 6 (19,500-26,000 lbs)
Fuel type	Diesel
Fuel economy (loaded)	4 km/l
Payload	7 tons
Cargo area	
Width (m)	2.4
Height (m)	2.4
Length (m)	7.3

The cost of importing the truck from the USA, which was found as the best option, is detailed in the following table:

Table 20: Break down of the truck's importing cost

Concept	Amount (GH¢)
Cost of the truck	18,000
Freight cost (roll-on roll-of)[15]	4,500
Insurance (1.5%)	270
Duties, fees and taxes[16]	3,780
Total cost	**26,550**

15 www.carexshipping.com/international-shippers-usa.html

16 Import duty (5%), VAT (12.5%), processing fee (1%) and other taxes (2.5%). Ghana Free Zones Board, 5th Link Road, East Cantonments, Accra

The two alternatives for mounting one or various containers on the truck are shown in Figure 19[17] and the break down of the cost of each of these alternative is detailed in Table 21:

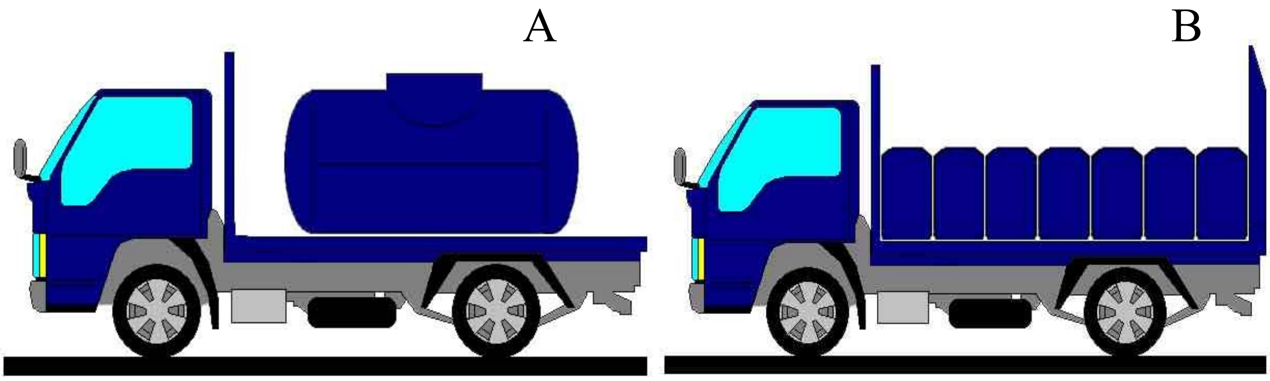

Figure 19: Transportation alternatives

Table 21: Complete cost of the equipped truck

Concept	Alternative A (GH¢)	Alternative B (GH¢)
Truck	26,550	26,550
Plastic tank (cap: 7000 litres)[18]	1,125	-
24 plastic drums (cap: 300 litres/drum)[19]	-	1,800
Diesel powered pump (40,000 litre/hr.)[20]	1,200	1,200
Total	**28,875**	**29,550**

Using these vehicles as a reference, the cost of transporting 7,000 litres of urine, which is the payload capacity of the truck, within a radius of 40 km from the source is approximately GH¢48 for both alternatives. In the Appendix C a complete description of this calculation, which assumes that during the return trip the truck comes back empty, is shown.

In Figure 20 a comparison between the value of the nutrients contained in 7,000 litres of urine (circa GH¢90) and its transportation cost to different distances is presented. As it can be observed, the maximum distance at which the cost of transportation does not exceed the value of the urine is approximately 90 km.

17 Drawings adapted from www.hiteque.net
18 Poly Tanks Ghana Ltd., South Industrial Area, Accra
19 This cost could also be avoided if drums from the biodiesel plant are to be used.
20 Cemix Ltd. Spintex Road, Accra

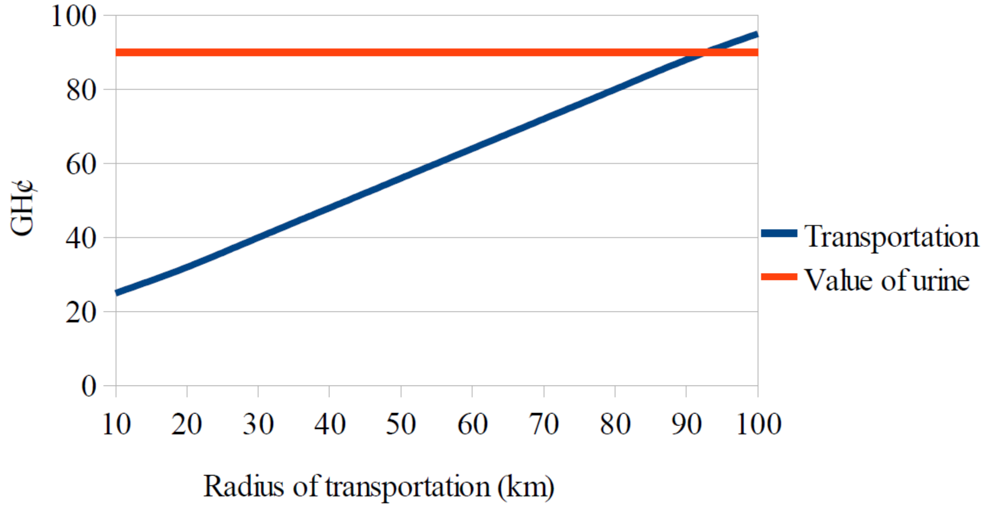

Figure 20: Comparison between the value of the nutrients contained in 7,000 litres of urine and its transportation cost to different distances

In addition, this information is useful to determine the maximum distance at which the storage facilities need to be located and the range of storage cost that can be allowed not to exceed the value of urine.

3.4 Storage of urine

As mentioned in Section 2.2.3, urine has to be stored for a certain period of time in order to be safe to be used in the field. Previous studies proposed that this storage may take place in big plastic tanks (Tettey-Lowor, 2008; Stoll, 2008), but due to the low value to volume ratio of urine this has proven not to be economically viable. Table 22 shows the costs incurred when urine is stored in such containers, the calculations were made considering a life span of 15 years for the plastic tanks:

Table 22: Costs of urine storage

Type of container	Capacity (litres)	Life span (years)	Price (GH¢)	Monthly cost of storage (GH¢/1,000 litres)
Plastic tank	30,000	15	3,970	0.74
Plastic bladder	30,000	8	600	0.20

As it can be observed, the final application that will be given to urine will impact directly its storage cost. For example, if urine will be used for fertilizing food crops that are to be processed, then one month of storage will be enough (refer to Table 2) and this will cost GH¢0.74 for each 1,000 litres of stored urine. If the intended use of urine is for fertilizing vegetables that are not to be processed, as is the case of most crops cultivated in urban farms in Accra, this cost climbs to GH¢4.4, which is almost 35% of the market value of the nutrients contained in that quantity of urine (refer to Table 16).

With the objective of reducing this storage cost various alternatives were explored and the one that offers the lowest cost is the use of plastic bladders designed to store big volumes of liquids, such as fuel, water, chemicals, etc. The following figure illustrates one of these bladders.

Figure 21: Bladder for storing bulk liquids

The CIF in the port of Ghana of a bladder with 30,000 litres capacity is GH¢600[21] and it has a life span of 8 years of repeatable use. According to this data, the monthly cost of storing 1,000 litres of urine is reduced to GH¢0.20 per month (refer to Table 22). The technical specifications of these bladders are shown in Appendix D.

Taking the above results and of the last section, the costs of transporting and storing 7,000 litres of urine for different cases are presented in Table 23.

Table 23: Comparison between different cases of transportation and storage of 7,000 litres of urine

	Transportation		Storage		Total cost (GH¢)
	Radius (km)	Cost (GH¢)	Period (months)	Cost (GH¢)	
Case 1	40	48	1	1.4	49.4
Case 2	40	48	6	8.4	56.4
Case 3	60	64	1	1.4	65.4
Case 4	60	64	6	8.4	72.4
Case 5	80	80	1	1.4	81.4
Case 6	80	80	6	8.4	88.4

21 Quotation obtained from Weifang Kracivi Trade Co. Ltd. on July, 2009 and based on a quantity order of 60 pieces

As it can be observed, Case 6 is the last scenario at which the costs of collecting, transporting and storing 7,000 litres of urine do not exceed the value of nutrients contained in them. If urine is stored in the fields were is to be used, then no further cost will be added. On the other hand, if it requires further transportation, this new cost needs to be added to the ones presented in Table 23.

3.5 Biodiesel processing plant

As mentioned in Section 2.6, this thesis proposes the use of urine for fertilizing oil palm in order to obtain oil that will be used to produce biodiesel. The main reason for it is that the large scale use of human excreta as a fertilizer might face the initial rejection of various sectors of society which would be concerned with the safety of this method to produce food. On the other hand, the production of fuel, which is a well demanded product, is a way to start benefiting from the fertilizing content of urine and reduce the risk of social rejection.

While the research of this thesis was carried out in Ghana, the facilities of the NGO Dumpong Biofuels were visited to evaluate the requirements of producing biodiesel at small-scale. This NGO is located in Dumpong Village, 25 km north of Accra and since 2007 has been promoting the production of biofuel using oil extracted from palm kernels, which are abundant in the area.

Although the design of small-scale biodiesel plants is widely available in the literature and over the internet, the plant presented in this work is based on the one owned by Dumpong Biofuels. Appendix E shows the break down of the cost of a plant with a daily processing capacity of 800 litres of biodiesel.

The process of producing biofuel using a vegetable oil as feedstock can be summarized as follows: methanol, catalyst and vegetable oil are mixed in a container and then are heated up to the reaction temperature and maintained there for a required amount of time. The ratio of the mixture, temperature and reaction time are defined for each type of oil. After the reaction time, the mixture is left aside and after approximately 8 hours the mixture will separate and glycerides will fall to the bottom of the container. Then the biodiesel, which lies at the top is removed by either tipping the container, pumping or syphoning the biodiesel. After that, the fuel has to be washed to remove any remaining glycerides, methanol or catalyst. This process is carried out by mixing pure water with the biodiesel and left to separate. After washing, water will fall to the bottom carrying the pollutants of the fuel. The last step is to recover the biodiesel from the top and put it in a well ventilated spot for a few days until it gets dry and becomes clear. At this point the biodiesel can be used to feed a diesel engine.

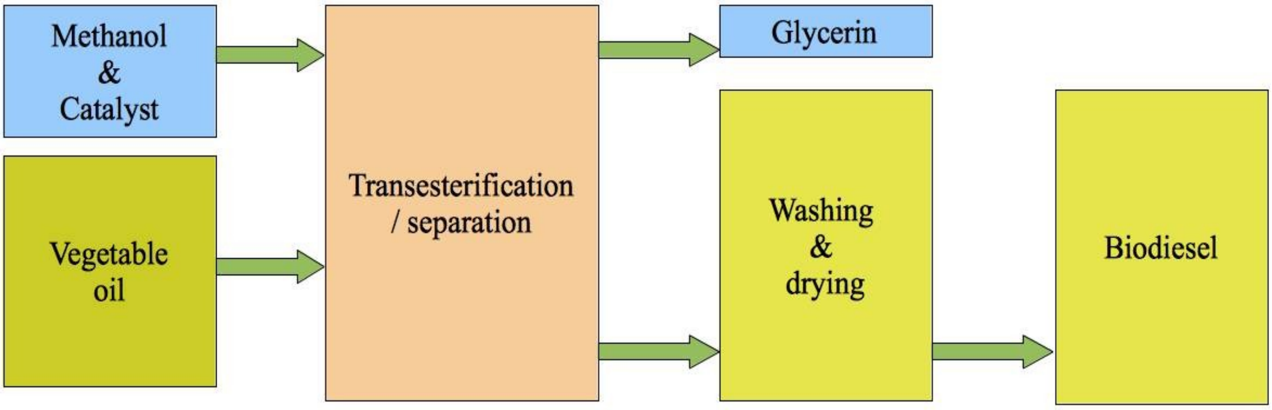

Figure 22: Biodiesel production process flow

Figure 23: Biodiesel obtained from different oils[22]

Attanatho et al. (2004) presented the formula for the synthesis of biodiesel from crude palm kernel oil. The conditions for this synthesis are as follows: use 1% NaOH as a catalyst, 1:3 mass ratio of methanol to oil and 120 minutes reaction time at room temperature, which allows the production of fuel without using electricity to heat the mixture. The estimated cost of producing biodiesel

22 utahbiodieselsupply.com

following this procedure is presented in Table 24. The expected yield according to Atanatho is 93%, which results in 3.7 litres of biodiesel and a final cost between GH¢0.81-0.85/litre (after adding the marginal cost of using the plant). Then, taking into account the price of petrodiesel in Ghana (GH ¢1.27)[23] and the ratio of 11:10 (refer to Section 2.5.2) that has to be considered to obtain the same heat of combustion, eleven litres of biodiesel would cost GH¢9.35 and ten of standard diesel GH ¢12.70. This makes it evident that biodiesel has an economic advantage of at least 35% with respect to the fossil fuel without taking into account the benefits to the engine, the environment and the fact that it is obtained from a locally produced oil.

Table 24: Biodiesel production cost (Attanatho et al., 2004)

Supply	Unit	Price (GH¢)	Quantity	Total (GH¢)
Oil palm[24]	litre	0.82	3	2.45
Methanol[25]	litre	0.53	1	0.53
Catalyst (NaOH)[26]	kg	0.62	0.03	0.02
			Total	**3.00**

3.6 Case study of Accra

Cofie et al. estimated the quantity of urine that is generated within fourteen public urinals in the Central Business District (CBD) of Accra. It was also calculated that the nutrients contained in this urine were equivalent to 0.08% and 0.2% of Ghana's nitrogen and potassium imports in 2005, respectively. The urinals are licensed by the municipality for their operation, and even if by contract the entrepreneurs are obliged to pay the dislodging service of a truck to dispose of the urine, it was found that the urinals were emptied into the drainage, which ends up in the Odaw River, the Korle lagoon or the Jamestown wastewater plant (after which it is released semi-treated into the Korle lagoon) (Tettey-Lowor, 2008; Cofie et al, 2007a).

23 Average price of diesel between September 2008 and September 2009, based on records from the Agricultural Research Station of the University of Ghana in Kade.
24 Price provided by GOPDC, on August, 2009
25 Quotation by Tin-Global Ltd, (September, 2009) CIF in the port of Ghana US$350=GH¢525/mt
26 Quotation by Tianjin Chemicals Co. Ltd, (September, 2009) CIF in the port of Ghana US$410=GH¢615/mt

Table 25: Urine generation within the CBD of Accra, adapted from Cofie et al. (2007a)

Location	Urine (litres/day)	Position in the map (Figure 24)
Kojo Thompson Road Makola Market	1,100	1
Nkrumah Avenue 2	980	2
Nkrumah Avenue 1	840	3
Rawlings Park 1	640	4
Kinbu Road	600	5
Kantamanto 1	600	6
Kantamanto 2	560	7
Rawlings Park 2	550	8
Kantamanto 3	520	9
Novotel Mkt. 1	290	10
Novotel Mkt 2	160	11
Tema Station	160	12
Metro Mass Transit Station	120	13
Mobil – Independence Avenue	120	14
Total	**7,240**	

The following figure presents the location of the urinals in the CBD, as it can be observed all of them are located within a radius of one kilometre, which could facilitate the collection of urine.

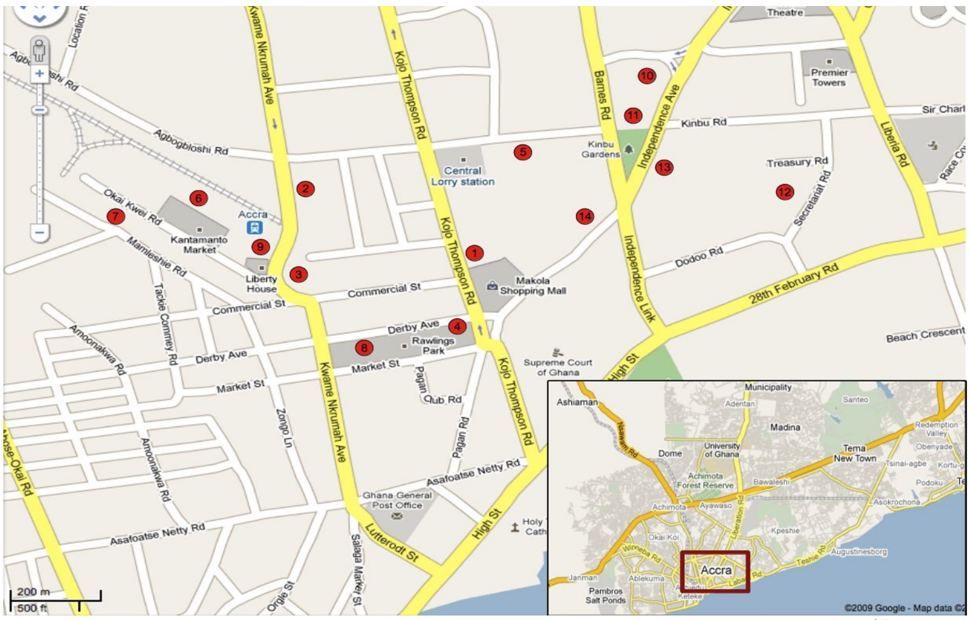

Figure 24: Location of public urinals in the CBD of Accra[27]

The proposed storage facilities for the urine collected in Accra are located in the semi-urban settlement of Nsawam, which is located 30 km north of Accra and is surrounded by abundant oil palm fields (Figure 25). Using the highway Accra-Nsawam, which is under construction, the transportation time outside of rush hours would be approximately 40 minutes, departing from the centre of Accra.

The land needed for storing the urine has a yearly rent cost of GH¢50/ha or it may be stored without any cost by oil palm farmers willing to use it. There, also the faeces might be composted and after the treatment takes place the hygienized excreta can be used to fertilize the fields.

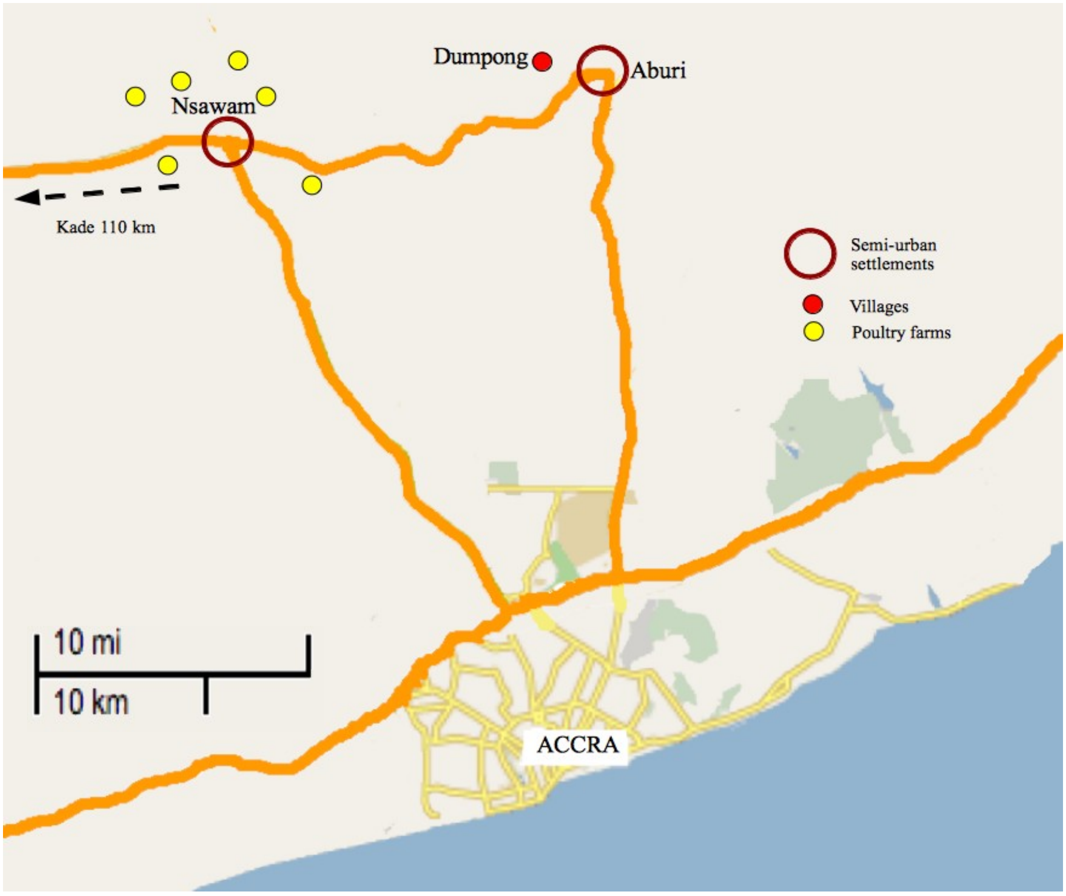

Figure 25: Location of Nsawam and Dumpong Village[28]

To avoid the traffic in the city, the collection of the 7,000 litres of urine can be carried out during the night. At this time it will be easier for the truck to find parking place in the congested CBD. After the collection has taken place, the truck will transport urine to Nsawam and discharge it during the morning.

In order to reduce the urine's cost of transportation, other options of cargo were explored for using the truck during the rest of the time and also to take advantage of the availability of cargo space

27 Adapted from Google Maps
28 Adapted from Google Maps

during the return trip. The best option found for achieving this objective was to bring poultry dung to Accra during the return trip. This manure is abundant in the farms located in Nsawam and its surrounding region. Currently, the price of each tonne of poultry dung in the farm, including the uploading to the truck is GH¢16, and is packed in 50kg-sacks.

According to Tettey-Lowor (2008), the consumption of poultry dung in vegetable urban farms in Accra is 150 sacks of 30-35kg (circa 5 tonne) per hectare, assuming a similar consumption in the rest of the farms presented in Figure 26, there is an estimated demand for 6400 tonnes a year (17 tonnes a day) of poultry dung in the city. Farmers in Accra currently pay the delivery and return trip to the farms in Nsawam and the cost of transportation is approximately GH¢8/ton, which is usually carried out in light duty trucks, capable of transporting 3.5 tonnes at a time. If the truck proposed in this project is loaded with 6-7 tonnes during the return trip and charges GH¢8/ton, it could generate up to GH¢56 that may contribute to reduce or even cover the transportation cost of taking urine and faeces out of the city.

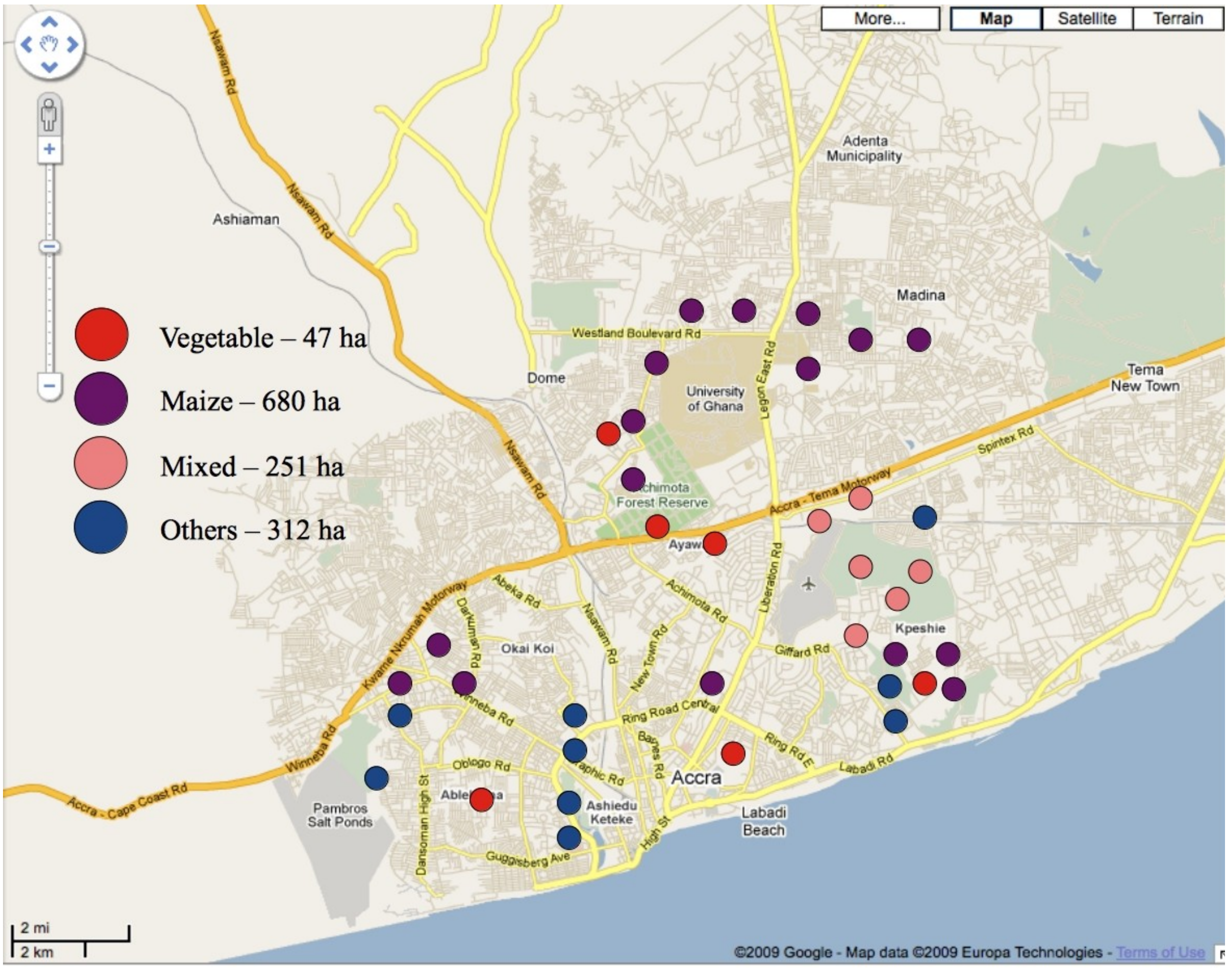

Figure 26: Farming activities in Accra adapted from Obuobi et al, (2006)

Figure 27 presents the proposed arrangement of the load of the truck for the return trip to Accra:

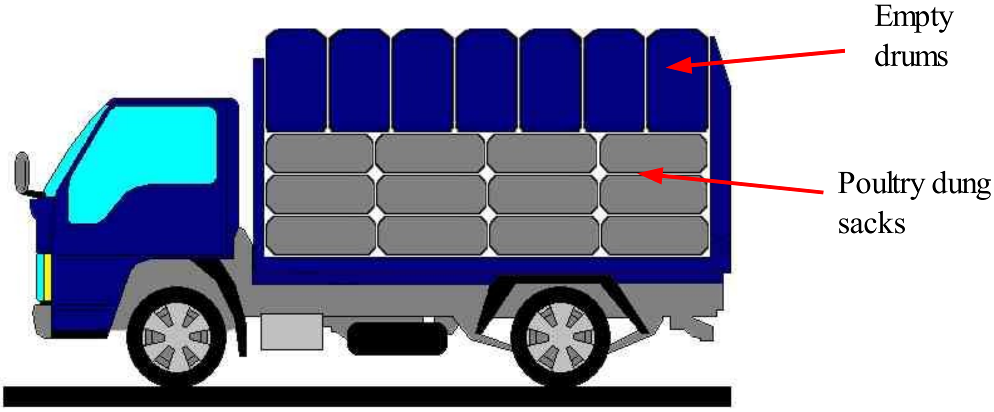

Figure 27: Arrangement for the trip Nsawam-Accra

As it can be observed, the use of plastic drums instead of a 7,000 litres container offers more flexibility to rearrange the load in the truck for alternative uses.

During the day, the truck can be also used to transport the FFB to the oil palm mills and the extracted palm oil to the small-scale biodiesel plants that might be located in Nsawam or to the facilities of Dumpong Biofuels, which are located 20 km east of Nsawam.

Following, is a summary of the estimated costs and revenues for the yearly collection of urine within the CBD, assuming that 7,000 litres will be collected every day, thus resulting in an amount of 2,555,000 litres/year.

Table 26: Estimated costs and revenues from urine collection in the CBD

Concept	Cost/Revenue (GH¢)
Upgrading all fourteen public urinals in CBD to store urine	-10,850
Yearly cost of transporting urine from the CBD to Nsawam	-17,520
Yearly cost of storing urine	-511
Yearly value of nutrients contained in urine	32,627
Income from transporting poultry dung from Nsawam to Accra (GH¢7/ton is assumed)	17,520
Total	**21,266**

3.7 Case study of Kade

During the research stage of this thesis, the proposed UDDT was presented to Mr. Osei Brako II[29] and Mr. Mawutor Daniel[30] and they expressed their willingness to install one of such facilities to reduce their sanitation costs and also to recover the nutrients that can be used in the oil palm plantations that they own (for the detailed cases refer to Sections 3.9.2 and 3.9.7), also the Agricultural Research Station of the University of Ghana in Kade (ARS) is planning to build a flush-toilet complex for its dwellers but Dr. Godfred K. Ofosu-Budu[31] has expressed his commitment to lobby for the construction of an UDDT instead. After receiving such a positive reception to this kind of toilet facilities, it will be assumed that some other villages and educational institutions in the Kwaebibirem District, could be willing to install UDDTs as well. Figure 28 presents the distribution of towns and villages around Kade, which could be potential sources of urine and faeces that need to be transported. As it can be observed, these settlements are situated from each other at a distance that is no more than 6 km. Thus, making the collection and transport of urine cheaper. Also, the oil palm fields are located in the vicinity, thereby the storage facilities could be spread in convenient sites of the district.

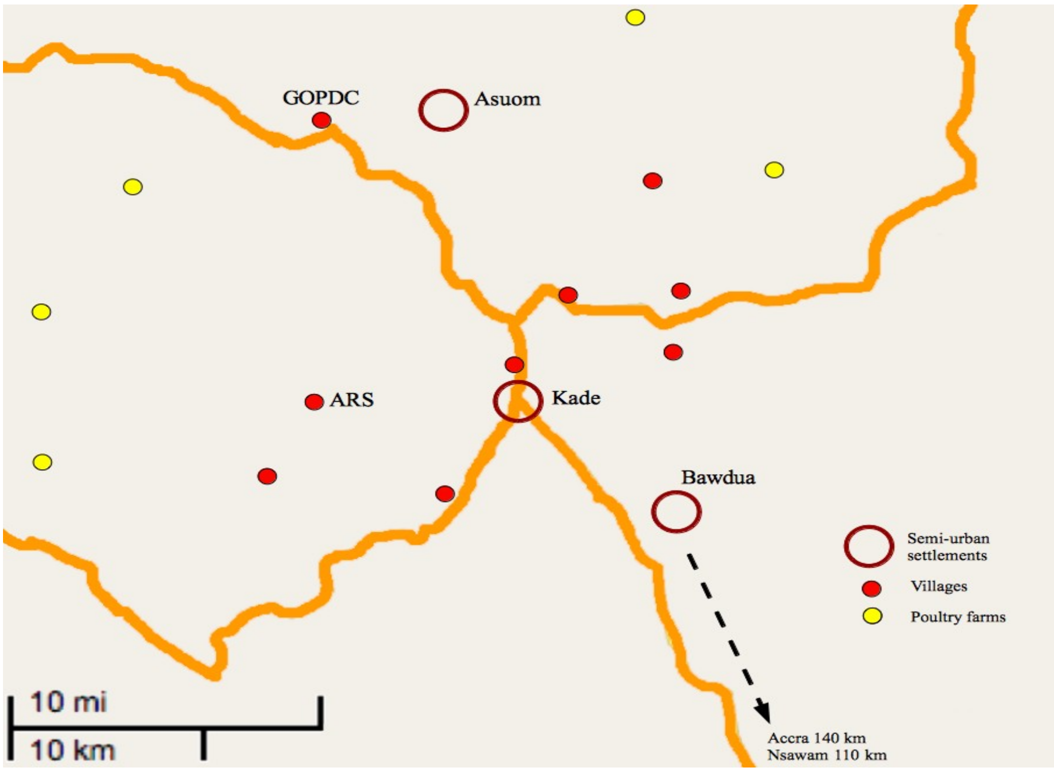

Figure 28: Location of urban and rural settlements near Kade

According to Dr. Ofosu-Budu, the fertilization needs of an oil palm are the following:

29 Chief of Damang Village, Kwaebibirem District
30 Managing Director, Adventist Preparatory and Junior High School, Kade, Kwaebibirem District
31 Senior researcher at the Agricultural Research Station of the University of Ghana in Kade, Kwaebibirem District

Table 27: Fertilization needs of each oil palm tree

Year	NPK 16-16-16 (kg/tree)	Organic NPK 3-2-13 (kg/tree)	NPK 12-17-2 (kg/tree)
1st	0.75	3.0	-
2nd	1.0	6.0	-
3rd	1.5	6.0	-
4th year and above	-	6.0	1.5

Taking the nutrients present in human excreta from Table 15, the equivalent amount of urine required to satisfy the nutrient needs of each oil palm tree are:

Table 28: Litres of urine needed to satisfy oil palm needs (litres/tree)

Year	Nitrogen	Phosphorus	Potassium
1st	35	255	189
2nd	57	399	348
3rd	70	513	376
4th and above	60	536	299

As it can be observed, if urine is used to satisfy phosphorus and potassium needs, then nitrogen requirements of the tree will be fairly exceeded. One alternative to avoid this potential waste of nitrogen is to use poultry dung and empty fruit bunches (EFB) to complement the fertilization of the oil palm. Poultry dung is rich in phosphorus (Bhattacharya et al., 1975) and EFB in potassium (Adamtey, 2005) and both are abundant in the region. Taking into account that an average of 135 oil palms are planted per hectare in the district, it would be needed to apply 8,100 litres of urine per hectare to satisfy the nitrogen needs of the oil palm.

Regarding the production of biodiesel, Dr. Ofosu-Budu also expressed his interest in setting one small-scale processing plant, since the ARS consumes more than 10,000 litres of petrodiesel a year. This represents a yearly expenditure of almost GH¢13,000, which could be reduced if part of the palm oil that they harvest could be converted into biofuel.

Another option proposed in this thesis is the use of sanitized excreta to fertilize fast growing trees for sustainable production of fuel wood and charcoal. According to the official statistics, 89% of the households in Ghana use these biomass for cooking. Even in Accra where the use of liquefied petroleum gas is more extended, 61% of households still use fuel wood or charcoal for cooking (GD, 2009). Charcoal production contributes greatly to the deforestation in the country, which is calculated at 115,000 ha/year (Mombu et al., 2008). The district where Kade is located has plenty of deforested land caused by bush fires, illegal chain saw operations and overexploitation of forest resources (GD, 2009).

The variety of fast growing tree proposed in this thesis is the Paulownia tormentosa, which has been grown successfully in trials in different African countries and has an annual wood production of approximately 37.5 tonnes per hectare (IDRC, 2001). The climatic and soil conditions in Kade and the surrounding region satisfy those needed for a successful growing of the tree (Table 29).

In Accra, each tonne of fuel wood has the value of GH¢150. It is transported from the Eastern Region at a cost of GH¢50/ton. Then, the cost of the wood itself is approximately GH¢100/ton. If urine is used to fertilize fast growing trees the value of wood that could be produced in each hectare is approximately GH¢3,750 per year.

Table 29: Required climate conditions for growing Paulownia tormentosa

	Paulownia tormentosa[32]	Conditions in Kade[33]
Annual rainfall (mm)	500-1500	1100-1300
Altitude (m)	0-1500	150
Soil pH	5-8.5	5.4-5.9
Temperature (ºC)	20-30	25-29

For timber production it is recommended to plant 200 trees of Paulownia per hectare and fertilize each year with 170 kg of NPK 10-30-10. This derives in a yearly need of 17 kg of nitrogen per hectare, which can be satisfied by using 2,900 litres of treated urine (refer to Table 15) and since the wood is intended to be used as fuel, one month of storage is enough to hygienize it.

Since Kade is located in an oil palm area, a different supply chain for the implementation of ecological sanitation is proposed. It will be assumed that the heavy duty truck will be used 50% of the time to serve the UDDTs in the Kwaebibirem District and the rest of the time will be available for transporting different cargo in the area.

The load that can be carried during this time varies. Currently, the ARS does not own a truck for its cargo needs and hires the service of external providers. Each year the ARS produces approximately 2,400 tonnes of FFB, which need to be transported to the oil mills within the area. The cost of transporting all this cargo is about GH¢15,000, if transported within a radius of 20 km, or GH ¢22,000 for a maximum distance of 40 km[34].

32 FAO - ecocrop.fao.org
33 Data provided by the ARS, Kade
34 Costs provided by GOPDC

Apart from that, the ARS nurses seedlings of oil palm, plantain and citric, which need to be transported to different places around the country. As an example, when the ARS needs to transport up to 4 tonnes of cargo to Accra, the service provider charges between GH¢150 and GH¢200, and the truck drives empty during the return trip. The ARS also buys poultry dung and pays GH¢8 for transporting each tonne of it from the poultry farm to the field. In addition, GOPDC also hires external services to transport part of the FFB that is bought from small oil palm plantations. Thereby, there is plenty of year-round work to keep the truck used.

3.8 Interaction between sanitation supply chains of Accra and Kade

Apart from serving the local transportation market, the truck in Kade could also be used to transport the fuel wood that might be produced in that region if fast growing trees are planted and fertilized with urine.

The wood can also be used to produce charcoal, which is usually brought from Nkoranza, a town located 175 km north of Kade. In this town, each tonne of charcoal is sold for GH¢40 and the cost of transporting it to Accra is GH¢100/tonne. If charcoal is produced in Kade, it would cost GH ¢27/tonne to transport it to Accra. The other two products that are often transported to the capital city are seedlings and palm oil. In the long term, if a large-scale biodiesel processing plant is settled in Kade, the biofuel might also be brought for its distribution in Accra. For the return trip to Kade, the truck could transport the metal drums with methanol and the sacks of potassium hydroxide that are needed as inputs for the biodiesel production.

Figure 29 shows the geographical position of the different settlements that might be involved in these interactions:

Figure 29: Geographical location of Accra, Kade, Nsawam and Dumpong

Finally, Figure 30 illustrates the proposed supply chain for the region Accra-Nsawam-Dumpong and Figure 31 for the region Kade-Kwaebibirem District. The transportation of urine is not shown in

Figure 31 because it is assumed that the storage facilities are spread along the oil palm plantations located everywhere in the district

Figure 30: Supply chain Accra-Nsawam-Dumpong

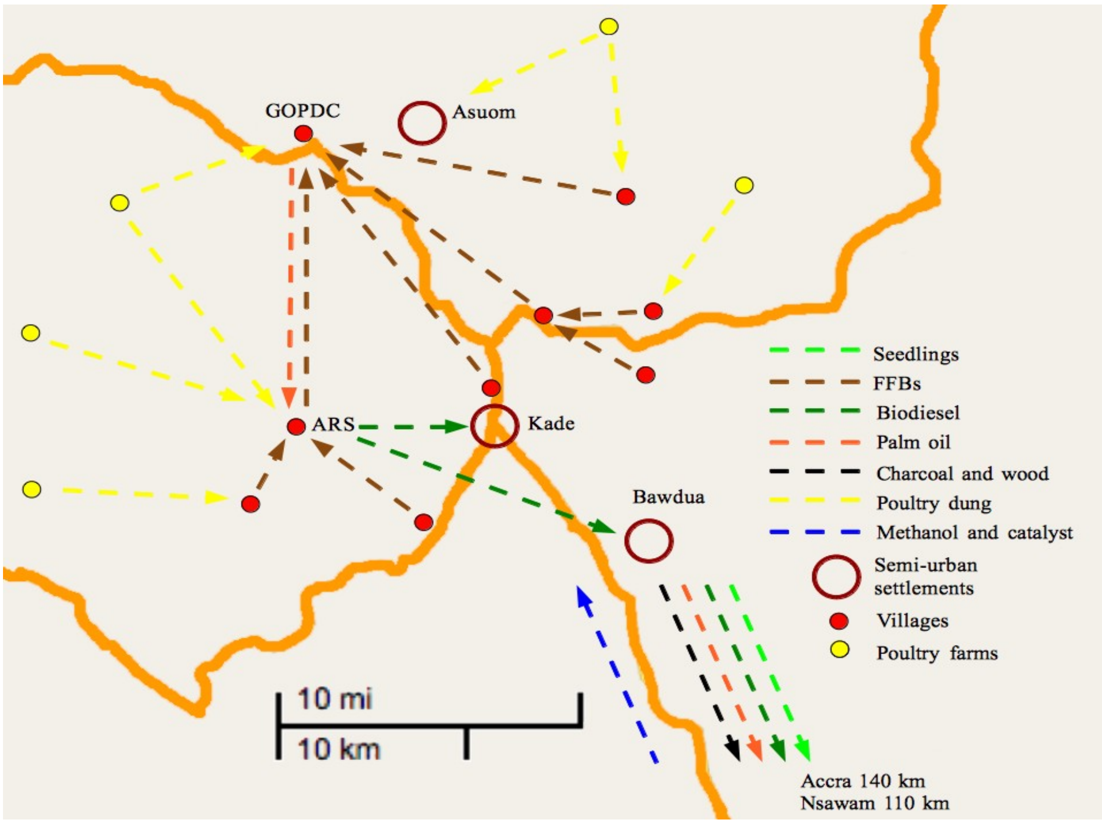

Figure 31: Supply chain Kade-Kwaebibirem District

3.9 Stakeholder analysis

In this section the groups that might be benefited or affected by the execution of the project proposed in this thesis are identified. The aim of this analysis is also to determine how much could each group contribute or affect to the success of the project. The results will be used to asses the proper course of actions that might be needed for an effective implementation of a large-scale ecological sanitation system in Accra and Kade.

3.9.1 Society

The society as a whole is the primary stakeholder that will benefit from the implementation of a large-scale ecological sanitation project. People will be the intended users of the improved sanitation facilities and will profit from the reduction in environmental pollution. If the loop of sanitation is closed by using sanitized excreta to grow crops, the society will have a reliable source of food. Those people currently lacking household toilets might benefit from a well-maintained communal or public sanitation facility.

The society might expect commitment from their political leaders to support the sanitation program and use it to solve the problems of lack of sanitation and environmental pollution that are very common in urban and rural areas in Ghana. For helping in the finance of such a program, the society may be willing to commit the resources that they already spend on sanitation procurement, such as the user's fees paid in public toilets, the expenses incurred in the construction of new toilet facilities and also their maintenance and operation costs, i.e. water bill and sceptic tank desludging.

One important aspect that will certainly influence the success or failure of this project is the willingness of people to change their habits and adapt to a new form of sanitation. It has been demonstrated that in ecosan projects across Africa the total acceptance of people affected by the implementation of the ecosan concept was a determinant factor of project's failure or success (Geller et al., 2008; McConville, 2003).

The perception of the Ghanaian society about buying vegetables fertilized with human excreta is already negative (Obuobi et al., 2006), so a well planned campaign addressing the concerns of people towards the consumption of food fertilized with sanitized excreta is critical for the success of the project.

The Ghanaian society has a deep respect for their educational and religious institutions, but this is not the same with regard to their politicians, who are frequently accused of being corrupt and inefficient. This has to be taken into account when promoting the benefits and commitment need to implement a new sanitation concept.

The power and influence that the Ghanaian society could have over the successful implementation of this project is directly related with the persuasion that they may exert over the decision makers. The society is by itself a decision maker, because each individual is able to decide on using the old sanitation approach or the sustainable one. What is more, the society as a whole has the power to influence the politicians to implement the new sanitation concept on a bigger scale, creating network effects that could boost the rate of usage of the ecological sanitation concept. The power of the society can also be understood as their willingness to follow the course of action needed.

If the current sanitation problems of the society are not properly addressed and solved by this project, then it can not be deemed a “success”. Thereby, the priority for this endeavour is to satisfy the society's needs.

3.9.2 Oil palm industry

Large- and small-scale oil palm producers are currently willing to find a reliable alternative to mineral fertilizers, the prices of which are generally unstable and always depend on external factors, such as the oil prices and the world demand for food and non-food crops.

Mr. Emmanuel Wiafe[35] stated that the current price of fertilizers made their use unaffordable, even for big scale producers like GOPDC. This year they have not applied any fertilizer at all to their oil palm plantation and they are considering not fertilizing for as long as three consecutive years in pursue of lower prices. This, of course, has an effect on the yield of oil palms, but according to the interviewee after considering all the pros and cons the decision of not fertilizing seems to be the best one. At the same time, GOPDC's plantation has a permanent population of 500 dwellers and 1200 temporal employees. These represent a huge potential of fertilizer recovery if the existing sanitation facilities are upgraded to permit the separate collection of faeces and urine.

On the other hand, most of small-scale oil palm producers have no knowledge about the use of fertilizers and the benefits from higher yields that they might provide. Mr. Brako II, is a chief in a village with more than 5,000 dwellers and owns a 250 ha oil palm plantation, where no fertilizer has ever been used, not even the waste from the oil extraction, which could be composted and is rich in potassium. The current yield of Mr. Brako's plantation is 6 tonnes of FFB per hectare, when in a well managed and fertilized farm it can reach up to 15 tonnes per hectare. At the same time, the inhabitants of the village pay GH¢100 each time they want to desludge a 7000 litres septic tank and

35 Research engineer at Ghana Oil Palm Development Company, Kwae, Kwaebibirem District

they also have a school with 500 children, which also pays for desludging services.

The lack of fertilization has resulted in a yearly decrease of palm oil production in the village. Dr. Ofosu-Budu has estimated that if this situation persists, the oil palm cultivation in small-scale plantations in the region will not be profitable at all in the near future.

Oil palm small- and big-scale producers could benefit not only from the availability of fertilizers, but also from the production of biodiesel, which is a value-added product that requires a small investment for starting operations. In addition, by using a diesel generator, enough power could be produced to drive the machinery that is human-driven in these small-scale oil mills.

Mr. Brako II has expressed his willingness to implement the ecosan concept in his village if the money comes from an NGO or if he can get a low-interest loan that will be paid with the increase in palm oil production.

In the case of oil palm farmers, the concern about fertilizing their trees with hygienized human excreta does not seem to create a big problem. The oil palm fruits grow far from the soil and during the oil extraction process the fruits undergo a sterilization process that may help eliminate the producers' concerns of infections caused by residues of human excreta in the oil.

The oil palm producers play and important role in the successful implementation of the project, since they are the expected end-users of the fertilizer and also the producers of the feedstock for the fuel that is planned to be used in the transportation chain of the human excreta. If farmers willing to participate in the early stages of the project were too few in number, entire oil palm plantations could be leased from numerous farmers in Nsawam, who are willing to get rid of an ever-decreasing business. One of the producers in this region, Mr. Kwasi Bekoem[36], expressed his commitment to rent each hectare of his oil palm plantation for GH¢50 a year, arguing that he is too old to take care of it and that none of his descendants are interested in continuing running the business, which according to them, does not have any promising future. As mentioned before, each hectare of a well managed and fertilized oil palm plantation, could increase its production in 10 tonnes of FFB per hectare (refer to Section 2.5.1) each one of which was paid on average at GH¢88 during the first half of 2009[37].

36 Owner of 200 hectares of land in Nsawam, part of which is planted with oil palms
37 Information provided by GOPDC

3.9.3 Sanitation entrepreneurs

These stakeholders are important to the project because they are the owners of the collection points of human excreta.

Mr. Frederick Tettey-Lowor[38] heads an enterprise that is planning to build and lease toilet blocks in densely populated areas of Ghana. The first stage of the project looks at building toilet complexes with 20 showers, 20 toilets and 1 sale kiosk. In these facilities, little water will be used to flush the toilets and human excreta will be collected for further production of biogas and organic fertilizer. The experimentation with UDDTs is considered for further stages of the project.

Mr. Tettey-Lowor is a sanitation entrepreneur committed to the dissemination of the ecosan concept across the country. He carried out his master thesis on this topic and during his research he identified that one of the barriers that must be overcome is the transportation of urine to farms at a competitive price. That is why he is now managing the Safi Sana project to start providing improved sanitation to his fellow citizens and lay the foundations for large-scale implementation of the ecosan approach in the country (Tettey-Lowor, 2008).

During the data collection for his thesis, Mr. Tettey-Lowor found out that some owners of existing public toilets in Accra were aware of the potential use of urine as a fertilizer, but that they did not discover how that product could be marketable. Also, they considered the disposal and transportation of urine as very expensive and impractical. Mr. Tettey-Lowor found that some of the public toilet owners were also willing to lease some urinals for experimental purposes.

The direct benefits for the owners of the existing public toilets, if they convert their facilities to UDTs or UDDTs, are the reduction of water consumption and desludging costs. The extra cost that these stakeholders might bear are the conversion costs, which in the long term are lower than the operation costs of their current facilities.

The willingness of these stakeholders to participate is of vital importance, since the supply chain of the project considers their location and daily production of human excreta as crucial inputs for the process.

3.9.4 Waste treatment sector

Since the Waste Management Department is only capable of collecting 60% of the waste generated in the city (Owusu-Boadi, 2002), the successful implementation of this project will help to relieve them from the excessive load that they currently bear.

38 Program Manager, Safi Sana Ghana Ltd. (founded by Dutch NGO Aqua for All)

Companies that charge for desludging septic tanks might be affected by the decrease in demand for their service. However, this decrease might not be perceivable because a limited amount of public toilets is expected to participate in the project and the market for desludging services comprises all the septic tanks in the city. If the project succeeds in applying the ecosan concept on a bigger scale, the existing infrastructure of the desludging companies may be lost because their septic trucks will not be longer required, which may represent a risk to the project since these groups might be trying to hinder its implementation in order to save their business.

One possible solution to this threat could be to convince the society, by means of facts, that the new sanitation approach is a better option to the existing system. As the society has the power to decide which approach to use and also to influence their decision makers, the risk of hindrance from the affected groups might be decreased.

3.9.5 Agricultural sector

This sector is one of the most favoured ones among all the stakeholders since a reliable source of locally produced fertilizer at an affordable and stable cost might become available. Their participation in the project is of utmost importance since they are the intended users of hygienized human excreta and an important echelon in the goal of closing the loop of sanitation. Previous studies have found that some of the urban farmers are aware of the use of human excreta as a fertilizer and many of them would be willing to pay the cost of transporting urine from the place where it is produced to their farms (Tettey-Lowor, 2008), but one aspect that these studies have not considered is the storage cost, that has been explained in the Section 3.4, and which if not addressed properly may be enough to make the use of urine uncompetitive compared with the use of mineral fertilizers.

The agricultural sector will not only benefit from using of fertilizer, but also from obtaining biodiesel at an affordable cost. Mr. Frank Aidoo[39], a pineapple grower in a region located 25 km north of Accra, finds that one of the most difficult things for marketing of his products is the lack of resources and infrastructure to sell it in parts of the country where the demand is higher. Often, the cost of transportation is unbearable and that is why the farmers are dependent on intermediaries to commercialize their products.

In the region where Mr. Aidoo's farm is located, oil palm kernels are thrown away because the small-scale mills do not find it profitable to obtain oil from them. Mr. Aidoo has started to extract oil from these palm kernels and is currently converting it into biodiesel. This source of energy is

39 President of the Dumpong Pineapple Growers and of Dumpong Biofuels NGO

now used to run a 15 KVA generator some hours a day, which provides the electricity to power a pump to deliver water for irrigation. He is also running a small water bottling plant and selling its product successfully in the surrounding area, without it being connected to the electrical grid.

Currently, Mr. Aidoo is looking to replicate this model of converting palm oil into biodiesel to boost the agricultural activities of the farmers in his region.

3.9.6 Government

The benefits that the government might expect from this project are the provision of adequate sanitation services to the population and also a reduction in environmental pollution. In addition, subsidies to other sectors, such as agriculture, health care, water treatment and waste management, might be expected to decrease. The project could also contribute to the accomplishment of the goals established in the Strategic National Energy Plan, which gives high priority to the production of biofuels in the country.

The economic resources that the government might need to spend on the promotion of ecological sanitation could be given through loans or subsidies to the individuals willing to build or upgrade their existing toilet facilities to UDTs, UDDTs or other ecosan technologies.

The relative power and influence that the government has over the rest of the stakeholders is crucial for the successful implementation of ecological sanitation in Ghana. It is through regulation and law enforcement that the government internalizes the effects derived from actions that pollute the environment. In addition, the government is in the position to monitor the well functioning of the project through its various agencies and institutions, which were created to bring support to many sectors of the society. The government might also act as an intermediary for getting the technical assistance required by the project.

The Ghana Energy Commission (GEC) is the branch of the government that regulates, manages and develops the energy resources in the country. It is through this commission that projects related to renewable energy in Ghana are funded and/or licensed. The GEC gives preference to endeavours devoted to renewable and efficient use of energy.

When the project proposed in this thesis was presented to Mr. Kwabena Otu-Danquah[40], he was very enthusiastic and commented that the GEC could provide technical support and assistance to run a pilot project for the part of biodiesel production. He mentioned that they could also assist in connecting and organizing stakeholders interested in the project.

40 Renewable Energy Chief, Ghana Energy Commission, Accra

According to Mr. Otu-Danquah, the GEC might be interested in supporting this project because it is related to the production of biofuel from renewable sources and also by the fact that it can be replicated throughout the country, not only to foster the production of biofuel with palm oil, but also with other kind of feedstock, such as jatropha seeds, which produce a non-edible oil and could be also fertilized with treated human excreta.

The GEC might benefit from the implementation of this project due to the fact that it will promote the creation of affordable energy supplies and increase the energy reliability within the country. The support of this commission is of vital importance to the project as they are intermediaries between the government and the society and they also might help to implement and monitor the proper development of this endeavour.

Another governmental organisation consulted during the research stage of this project is the Environmental Protection Agency (EPA), which is the lead agency for environmental and conservation management matters. Among its different responsibilities, it is in charge of controlling the volume and effects of wastewater discharges to the environment and of promoting research for the improvement and protection of the environment.

The proposed project might be of interest to this agency for two reasons. Firstly, because if implemented on a bigger scale it will contribute to relieve the water bodies of the country from the massive discharge of untreated wastewater, and secondly, it will help to decrease the unsustainable exploitation of the forests for fuel wood and charcoal.

According to Mr. Oppong Boadi Kyekyeku[41], for a project of such nature, the EPA could assist with the oversight of the written proposal that needs to be submitted to the Ghanaian Ministry of Environment, Science and Technology, which would evaluate its feasibility and also decide how it would be sponsored. Contrary to the projects supported by the GEC, which are funded by taxes, the EPA helps to find the financial aid from other governmental institutions, NGOs or Multilateral Funding Sources, such as the United Nations Development Programme (UNDP) or the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit – GTZ), among others.

The EPA also provides technical assistance and helps to monitor and evaluate whether a project meets all the required environmental standards. At the same time, the Climate Change Unit of the EPA provides assistance for joining to the global carbon market, which is a good way to finance the biofuel production proposed in this thesis.

41 Principal Programme Officer, Environmental Protection Agency, Accra

According to Mr. Kyekyeku, not all biofuel-production projects can be financed through the carbon credit market. A lot of fossil fuel is employed in the agricultural, manufacturing and distribution processes that produce biofuels. For this reason, each production cycle must be assessed to prove that a real carbon emission offset occurs. The first impression of Mr. Kyekyeku to the scheme proposed in this thesis, is that it has a good chance of being approved, because the oil crops are going to be fertilized with locally obtained nutrients and also the supply chain could be powered with biofuel produced within the supply chain itself.

3.9.7 Educational institutions

The role that educational institutions play in the successful implementation of this project is very important, since these institutions have credibility and respect among the Ghanaian society. The influence that they may exert on the attitude of the population is crucial. The best example of this is the initiative taken by the Valley View University (VVU) located in Oyibi, within the Greater Accra Region, which is a private university operated by the Seventh-day Adventist Church. This university has taken the first step to introduce the ecological sanitation approach on a large scale by building the biggest complex of UDTs and UDDTs in West Africa. During one visit to the campus, Mr. Daniel Sarpong[42] highlighted the commitment that this university has in spreading the ecosan approach to the society and also to give the example to other institutions in becoming environmentally sustainable.

The VVU has demonstrated that the ecosan approach can be completely assimilated in the everyday life of its 3800 students. They experience the ecosan approach by bathing with collected rainwater, eating food cooked with biogas produced from greywater, using only UDTs and UDDTs and also by consuming fruits and vegetables fertilized with treated excreta.

In summary, the VVU is demonstrating that it is possible to close the loop of sanitation and is also giving the example to other institutions on how to become sustainable in many fronts.

As it can be observed, one advantage of turning to educational institutions for promoting the ecosan approach is that they concentrate hundreds of young people and children. Generally, each institution bears the costs of sanitation services for its students and they might benefit from upgrading their toilets to UDDTs, as the following case illustrates.

The Adventist Preparatory and Junior High School is a private educational institution located in Kade. According to Mr. Mawutor Daniel, its Managing Director, the school has 800 students

42 Ecological Sanitation Manager, Valley View University, Oyibi, Ghana

enrolled for this year and 200 more are expected in the following year. Currently, they have five flushing toilets and multiple urinals. The total investment on these sanitation facilities, only for the toilets, was of GH¢10,000 and Mr. Daniel estimated that they have a life span of five years, after which new facilities have to be built.

Mr. Daniel fully agreed that the UDDT proposed in this thesis, which has 6 toilets and an estimated cost of GH¢5500, represents a big opportunity to reduce their sanitation costs and a potential source of fertilizer for a 30 hectares oil palm plantation owned by the school. Regarding this plantation, he mentioned that no fertilizer or compost has ever been used in this farm and that their current yield is 2.5 tonnes of FFB per hectare, which is far below the yield of 15 tonnes per hectare that can be reached with appropriate management and fertilization.

Mr. Daniel stated the commitment of the school to provide the land and the investment for building an UDDT complex if the project proposed in this thesis is implemented in the future.

The Dumpong village also has a school attended by more than 200 children every day. Mr. Michael DiBenedetto and Mr. Jerry Robock, American members of Dumpong Biofuels NGO, are trying to address the problem of the lack of sanitation system in the school and the village, but they want to introduce a system that would be easy to repair. They have the concern that if there are mechanical parts, or a somewhat complicated design that could become dysfunctional, the villagers may not be able to fix it and the project could become obsolete. Thus, they became interested in the project proposed in this thesis as it seems to be very simple to repair and replicate, and because they have already installed a biodiesel processing plant in the village.

Clearly, one of the most important contributions that the educational institutions can make to the successful implementation of the ecosan approach is that they could promote this concept among the younger generation. It will make children feel identified with the system starting already from an early age, which will make them potential users and promoters of this concept as adults.

3.9.8 Research institutions

The participation of research institutions is also very important since they could help to implement, monitor and provide the scientific and technical assistance that is required in a project of this nature.

The International Water Management Institute (IWMI) is a scientific organization that has carried out an extensive research in the area of urban agriculture and use of municipal waste as a fertilizer in Ghana. Currently, Dr. Olufunke Cofie[43] is leading demo trials on the use of urine from public

43 Research Scientist, International Water Management Institute, Accra

toilets as a source of nutrients for vegetable production within the Accra metropolitan area. She is also responsible for the study that served as a base for the estimation of urine produced in the CBD of Accra used in Section 3.6.

Other scientists in the IWMI have done research on the perception of farmers and consumers regarding the use of treated human excreta as a fertilizer (Danso et al. 2006; Danso et al., 2004), which is a prime input for designing the campaign to promote the implementation of this new sanitation approach.

The support of the IWMI is very important since it can also contribute to disseminating the ecosan approach to other parts of the country. Dr. Cofie has expressed her commitment to providing assistance in new ecosan projects, such as the one that might be developed in the Dumpong village.

On the other hand, the ARS could also play a very important role in this endeavour. This institution runs trials on new ways of fertilizing crops that are cultivated in the country as a part of its research. Dr. Ofosu-Budu very welcomed the idea of fertilizing oil palm with treated excreta and also made the observation that this fertilizer could be enriched with poultry dung and EFBs to satisfy the phosphorous and potassium requirements of the oil palm. As mentioned before, he has expressed his commitment to lobby for the construction of an UDDT in the ARS, which has a fixed population of 150 people, 100 temporary workers and houses a school with more than 500 students. Human excreta obtained from a complex like this could help to condition the 200 hectares of oil palm plantation that belong to the ARS, which are not currently fertilized due to high prices of nutrients.

Dr. Ofosu-Budu is also committed to spreading the word about the benefits of switching to the ecosan approach within the small- and large-scale palm oil producers in the region, who often come to him to get advice on fertilization matters for this crop. It is worth to mention that the support of a scientist like Dr. Ofosu-Budu could contribute strongly to the successful implementation of this project, since he is a well recognized and respected authority in the country regarding the use of organic materials for composting.

The research institutions that may participate in this project will also benefit by gaining experience in a field that has the potential to be replicated in most of the countries in SSA and other developing regions in the world. They might also be favoured by the recognition by the society for their contribution to solve problems that directly affect them, such as inadequate sanitation and all the environmental and health problems derived from it.

3.9.9 Religious institutions

As it has been observed in multiple projects around the world, the cultural and religious beliefs play an important role in the acceptance of new sanitation systems. In some of them, the prejudices against human excreta have prevented the proper operation of ecological sanitation systems: fear of being vulnerable to acts of witchcraft, taboos regarding shared toilets, even the fact of adding ashes to faeces could become a problem for the implementation of the project if not addressed properly. There are cultural beliefs that could even make people reject the idea of storing and treating excreta, especially if it is for agricultural purposes (McConville, 2003; Kaggua et al. 2003).

In Ghana, two religious groups with different conceptions towards human excreta exist. In the case of the Christian religions, prejudice against urine and faeces is usually related to hygiene and might be overcome if safe handling and treatment of them is guaranteed. On the other hand, the Islamic culture pays special attention to personal hygiene and requires Muslims to minimize any contact with human excreta (Quazi, 2005).

In the Ghanaian society, the opinion of well-respected religious leaders can influence the conduct of the people in a good way. These leaders can propagate the ideas of better sanitation approaches and also highlight its relation with the ethics of ecology and respect to the environment.

The execution of the project proposed in this thesis might be of interest to religious leaders, mainly because one of the main motivations of any church is the welfare of its members. The implementation of an ecological sanitation based system has the potential to improve the lifestyle of the people from various crucial aspects, which go from reducing diseases and infant mortality to improving human nutrition.

While the research for this project was carried out in Ghana, the Rev. Fr. Kwaku Dua-Agyeman[44] got to know about it and expressed his eagerness to share this concept with a colleague who manages a bigger congregation and to start promoting the use of treated human excreta as a fertilizer. Also, Mr. Dua-Agyeman is working on a personal project for cassava cultivation and plans to do some trials following the ecosan approach.

The successful implementation of this new sanitation concept among the different regions and cultures throughout Ghana requires the enthusiasm and involvement of religious leaders, such as Mr. Dua-Agyeman, who can promote new ecosan projects or even organize workshops for the dissemination of ecosan technology.

44 Director of the Anglican Retreat Centre, Accra

3.9.10 Non-Governmental Organisations

The solution of the problems addressed in this thesis, such as sanitation, food availability and environmental protection, is of interest to many humanitarian organisations.

NGOs concerned with nutrition problems might find it attractive to participate in the implementation of the ecosan approach to provide people in need with a reliable source of food. Other NGOs willing to alleviate poverty could find the production of biofuel for small-scale energy generation useful.

Aqua for All[45] is the Dutch NGO that helped to found Safi Sana Ghana Ltd. (refer to page 64). This NGO funds water and sanitation projects in developing countries and also invests in innovative developments that could help to achieve this goal. A project like the one proposed in this thesis might be of interest to Aqua for All and other NGOs that have the same objectives.

The Nature Conservation Research Centre (NCRC) was a non-profit organisation interviewed for this thesis. This Ghanaian NGO promotes the awareness and protection of Ghana's nature and wild species through conservation initiatives. It also develops conservation areas and facilitates field research.

Currently, one of their projects is related to moving charcoal production away from wild sourcing to sustainable exploitation (Mombu et al., 2008). Mr. Victor Mombu[46] commented that to achieve this objective, tangible economic returns are needed to motivate people to stop cutting down trees indiscriminately.

The NCRC encountered the fertilization of fast growing trees with treated excreta as a viable solution for fuel wood and charcoal production and are willing to make trials to promote the ecosan approach for reforestation of degraded lands.

The involvement of an NGO like NCRC could help to promote this project at a national level, since their members work in many regions of the country and its initiatives have also facilitated sustainable economic development in other nations in West Africa.

Another core contributions that the NGOs could make to the project are their capability to mobilize public support, since they are well appreciated within the West African society, mainly due to the fact that most of the foreign help provided has been brought to this region through these organizations.

45 www.aquaforall.nl
46 Program Director, Nature Conservation Research Centre, Accra. (ncrc-ghana.org)

4 Conclusions and recommendations

Having analysed the existing conditions of sanitation in Accra and Kade and having considered the previous research done in this field, it was observed that there is an opportunity for implementing sanitation systems following the ecosan approach. However, it can be constrained by the rejection that the society may have towards the use of excreta in agriculture and by the huge costs of collecting, transporting and treating excreta to be used as a fertilizer. Urine, which comprises most of the volume of human excreta, has a low value-to-volume ratio, which makes it expensive to transport and store it for long periods of time, such as those required for its proper hygienization.

Considering these facts, the way of implementing a large-scale ecosan based sanitation system has been proposed in this thesis. The main advantages of this proposal are its low cost compared to other sanitation approaches, the efficient use of the cargo capacity of vehicles involved in the supply chain and a considerable decrease in storage costs for urine. In addition, the risk of social rejection to this sanitation approach is reduced by using the treated excreta for producing a sort of widely demanded biomass-based fuels, such as biodiesel, charcoal and fuel wood.

The implementation of a project like the one proposed in this thesis could help to fulfil the interests of many groups that are going to be directly or indirectly affected by it. The society has been identified as the key stakeholder of this endeavour, since they are the intended users, beneficiaries and also the sector which holds most of the power needed to make this project successful. Other important stakeholders that will directly benefit from this project are the owners of public toilets, the palm oil producers, and the agricultural sector in general.

The government, NGOs and the educational, research and religious institutions are also beneficiaries, but at the same time they provide additional help by funding, promoting, implementing or monitoring this endeavour. The committed involvement of politicians, religious leaders, respected persons and institutions is of great importance to promote a favourable change in how people perceive this new sanitation approach. Some of the main interests of each of these stakeholders would be satisfied if the project succeeds, such as employment generation, sanitation improvement, environmental sustainability, among others.

With regard to the time of implementation of this project, this could be started immediately and requires a reasonable low investment. Also, as seen in the analysis, the majority of stakeholders have already shown enthusiasm in participating in this proposal if implemented. Some of them are ready to finance the construction of an UDDT to reduce their sanitation costs. The government could help to fund the project through its various agencies and institutions. The researchers at IWMI are working on alternatives to use urine from public toilets in vegetable production. The ARS is eager to do trials on composting urine with poultry dung and EBFs to nurture oil palms.

If the project proposed in this thesis succeeds in its implementation, the possibility exists that it can be applied to other areas not only in Ghana, but in countries where similar conditions occur. Of course, this has to be done bearing in mind local conditions and the need to tailor any project to them.

There are few years left to accomplish the goal set by the United Nations of providing improved sanitation to 63% of the population in SSA by 2015. This means that there is an enormous challenge of giving access to this kind of facilities to 370 million people within the next six years.

The need is there, the challenge is huge, a tentative sustainable solution has been proposed and the opportunity of closing the loop of sanitation is closer.

In short: it is time to act.

Bibliography

Adamtey, N., 2005, Recycling and evaluation of agricultural and agro-industrial residues for agricultural use in Ghana. A case study in the Kwaebibirem District. M.Phil Thesis, School of Research and Graduate Studies, Faculty of Science, University of Ghana, Legon.

Attanatho, L., Magmee, S, Jenvanitpanjakul, P., 2004. Factors Affecting the Synthesis of Biodiesel from Crude Palm Kernel Oil. Environmental, Ecological and Energy Department, Thailand Institute of Scientific and Technological Research, Thailand.

Bhattacharya, A., Taylor, J., 1975. Recycling animal waste as a feedstuff. Journal of Animal Science 41:1438.

Boost, M., Poon, C., 1998. The effect of a modified method of lime-stabilization sewage treatment on enteric pathogens. Environment International, Vol. 24, No. 17, 783-788.

Cockerhill S., Martin C., 2008. Are biofuels sustainable? The EU perspective. Biotechnology for Biofuels, Vol. 1.

Cofie, O., Mainoo, O., 2007a. The Potential for Urine Recovery and Reuse in densely populated districts within the Accra Metropolitan Area (Unpublished work).

Cofie, O., Kranjac-Berisavljevic, G., Drechsel, P., 2007b. The use of human waste for peri-urban agriculture in Northern Ghana. Renewable Agriculture and Food Systems, Vol. 20, No. 02, 73-80.

CWIQ, 2003. Core Welfare Indicators Questionnaire Survey, Ghana. Available at: www.statsghana.gov.gh, accessed on July 8th, 2009.

Dagerskog L., Kenfack, S., Jönsson, H. 2008. Ecosan Fertilisers with Potential to Increase Yields in West Africa. Urban Agriculture magazine. No. 20, 41-43.

Danso, G., Drechsel P., Fialor S., Giordano, M., 2006. Estimating the demand for municipal waste compost via farmers' willingness-to-pay in Ghana. Waste Management Vol. 26, No. 12, 1400-1409.

Danso, G., Drechsel, P. Gyiele L., 2004. Urban Household Perception of Urine-Excreta and Solid Waste Source Separation in Urban Areas of Ghana. In C. Werner et al. (eds.) Ecosan - Closing the Loop. GTZ and IWA, Germany, 191-196.

Demirbas, A., 2008. Biodiesel, A Realistic Fuel Alternative for Diesel Engines. Springer London.

Diao, X., Sarpong, D., 2007. Cost implications of agricultural land degradation in Ghana. An economy wide, multimarket model assessment. International Food Policy Research Institute, Discussion Paper.

Drechsel, P., Gyiele, L., 1999. The economic assessment of soil nutrient depletion—Analytical issues for framework development. In Issues in Sustainable Land Management 7. Bangkok: IBSRAM/SWNM.

Drechsel, P. and Graefe, S. and Sonou, M., Cofie, O., 2006. Informal Irrigation in Urban West Africa: An Overview. International Water Management Institute.

Esrey, S., Gough, J., Rapaport, D., Sawyer, R., Simpson, M., Vargas, J., Winblad, U., 1998. Ecological Sanitation, Sida, Stockholm.

FAO, Food and Agriculture Organization of the United Nations, 2005. Fertilizer use by crop in Ghana.

FAO, Food and Agriculture Organization of the United Nations, 2008. Current world fertilizer trends and outlook to 2011/12.

GBN, Ghana Business News, 2009. Available at: www.ghanabusinessnews.com, accessed on May, 7th, 2009.

GD, Ghana Districts, 2009. Available at: www.ghanadistricts.com, accessed on May 22nd, 2009.

GEC, Ghana Energy Commission, 2006. Strategic National Energy Plan 2006 – 2020. Available at www.energycom.gov.gh, accessed on July 25th, 2009.

Geller, G., Laryea, S., 2008. Cycles in the ecological development of Valley View University, Accra, Ghana. Access to sanitation and safe water. Available at: www.gtz.de, accessed on May 8th, 2009.

Germer, J., Sauerborn J., 2008a. Leaf area and yield response of urine fertilised sorghum: A field trial in Ghana. Available at www.gtz.de, accessed on June 17th, 2009.

Germer, J., Sauerborn, J., 2008b. Urine Diverting Dehydration Toilets to Harness Nutrients. An Estimation for Ghana. Available at www.gtz.de, accessed on July 15th, 2009

Ghana in Figures, 2005. Ghana Statistical Service. Available on: statsghana.gov.gh, accessed on May 7th, 2009.

GNA, Ghana News Agency 2009. Available on: www.ghananewsagency.org, accessed on August 13th, 2009.

Gregory, D., Bumb, B., 2006. Factors affecting supply of fertilizer in sub-Saharan Africa. Agriculture and Rural Development Discussion Paper 24, The World Bank.

Hargrove T., 2008. Urea tanks on diesel trucks -- that's the law in the United States starting in 2010. Available at: www.eurekalert.org, accessed on July 7th, 2009.

Hargrove, T. 2008. World fertilizer prices soar as food and fuel economies merge. The International Fertilizer Development Center Report, Vol. 33.

Hatfield, J., Prueger, J., 2004. Nitrogen Over-use, Under-use, and Efficiency. Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia.

Höglund, C. 2001. Evaluation of microbial health risks associated with the reuse of source-separated human urine. PhD thesis, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden.

IDRC, The international Development Research Centre, 2009. Intercropping with Paulownia - the "wonder tree" of China. Available at www.idrc.ca, accessed on August 15th, 2009.

Isherwood, K. 1998, Mineral fertilizer use and the environment. International Fertilizer Industry Association, United Nations Environment Programme.

Jitputti, J., Kitiyanan, B., Bunyakiat, K., Rangsunvigit, P., Jenvanitpanjaku, P., 2006. Transesterification of Palm Kernel Oil and Coconut Oil by Difference Solid Catalysts. Chemical Engineering Journal Vol. 116 No. 1, 61-66.

Johnston, M., Holloway, T., 2007. A Global Comparison of National Biodiesel Production Potentials. Environmental Science and Technology, Vol. 41, No. 23, 7967-7973.

Jönsson, H., 2004. Guidelines on the use of Urine and Faeces in crop production. EcoSanRes publications series, 2004:2, Stockholm Environment Institute.

Kaggwa, R., Kiwanuka, S., Okurut, O., Bagambe, F., 2003. Experiencias en la instalación de sanitarios ecosan en asentamientos costeros de Uganda, 2º Simposio Internacional sobre Saneamiento Ecologico, April, 2003.

Lienert, J., Haller M., Berner A., Stauffacher M., Larse, T., 2003. How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients (urine). Water Science and Technology

Vol. 48, No. 1, 47–56.

LIFE September 17, 1945, page 116.

McConville, J., 2003. How to Promote the Use of Latrines in Developing Countries. Unpublished paper. Michigan Technical University.

Ministry of Food And Agriculture, Ghana, 2009. Available at: www.mofa.gov.gh, accessed on August 22nd, 2009.

Mombu, V., Ohemeng, J., 2008. Towards sustainable charcoal production in Ghana. Negotiating a Community-based charcoal Association in Nkoranza District. Nature Conservation Research Centre, Ghana.

Morgan, P., 2003. Experiments using urine and humus derived from ecological toilets as a source of nutrients for growing crops. Paper presented at 3rd World Water Forum 16-23 March 2003.

Muttert, E. 1997. La Palma Aceitera , El Cultivo Dorado de los Trópicos. Informaciones Agronomicas, Instituto de la Potasa y el Fosforo, Vol. 29, 1-3.

Muttert, E., 1998. El potasio en la palma aceitera. Informaciones Agronómicas, Vol. 30.

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O., Raschid-Sally, L, Drechsel, P., 2006. Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. International Water Management Institute (IWMI), Network of Resource Centres on Urban Agriculture and Food Security (RAUF), Challenge Program on Water and Food (CPWF).

Otterpohl, R., 2001. Black, Brown, Yellow, Grey - The new colours of sanitation. Water, Vol. 21, 27-41.

Owusu-Boadi, K, Kuituen, M., 2002. Urban waste pollution in the Korle Lagoon, Accra, Ghana. The Environmentalist, Vol. 22, No. 4, 301-309.

Owusu, G, 2005. Small Towns in Ghana: Justification for their Promotion under Ghana's Decentralization. African Studies Quarterly, Vol. 8, Issue 2, 48-69.

PAA, Public Agenda Accra, 2009. /Available at: www.ghanaweb.com/public_agenda, accessed on August 5th, 2009.

Poku, K., 2002. Small-Scale Palm Oil Processing in Africa, FAO Agricultural Services Bulletin 148.

Quazi, A., 2005. Study of the reuse of human excreta in Bangladesh. A manuscript. International Water and Sanitation Centre & NGO Forum for drinking water supply & sanitation.

Rosemarin, A., Caldwell, I., 2007. The Precarious Global Geopolitics of Phosphorus. Paper presented in International Conference on Sustainable Sanitation, Dongsheng, China.

Rüd, S., Münch, E., 2008. Ecological Sanitation Projects from around the world and their links with the solid waste sector, GTZ.

Steiner, M., Montangero, A., Koné, D., Strauss, M., 2002. Economic aspects of low-cost faecal sludge management. Estimation of collection, haulage, treatment and disposal/reuse cost, EAWAG/SANDEC, draft under revision.

Stoll N., 2008. Potential Costs and Revenues of Ecological Sanitation in Accra, Ghana. Diploma Thesis. University of Hamburg, Germany.

Strauss, M., Barreiro, W., Steiner, M., Mensah, A., Jeuland, M., Bolomey, S., Montangero, A., Koné, D., 2003. Urban excreta management - Situation, challenges, and promising solutions. IWA Asia-Pacific Regional Conference, Bangkok, Thailand, October 19-23.

Tailliez B., Caliman J.P., Verwilghen A., Omont H., 2005. Scientific Research for Sustainable Palm Oil Production, Roundtable on Sustainable Palm Oil RT3, Singapore.

Tettey-Lowor, F., 2008. Closing the loop between sanitation and agriculture in Accra, Ghana. Master Thesis, Wagening University, The Netherlands.

UN, United Nations, 2008. Millennium Development Goals Report.

UNDESA, United Nations Department of Economic and Social Affairs, 2004. Ghana National Sustainable Development Report.

UNDESA, United Nations Department of Economic and Social Affairs, 2007. Small-Scale Production and Use of Liquid Biofuels in Sub-Saharan Africa: Perspectives for Sustainable Development.

UNEP, United Nations Environment Programme, 2004. Water Supply & Sanitation Coverage in UNEP Regional Seas.

UNEP, United Nations Environment Programme, 2006. The state of the marine environment: trends and processes.

USEPA, United States Environmental Protection Agency, 2002. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. Draft Technical Report. United States Environmental Protection Agency Air and Radiation.

Watkins, K., 2006. Human Development Report: “Beyond scarcity: Power, poverty and the global water crisis”, United Nations Development Programme.

Werner, C., 2006. Closing the loop through ecological sanitation.. Available at www.gtz.de, accessed on October 6^{th}, 2009.

WHO, World Health Organization, 2006. Guidelines for the safe use of wastewater, excreta and greywater - 3rd Edition.

WHO, World Health Organization, 2008. Progress on Drinking Water and Sanitation: Special Focus on Sanitation.

WHO, World Health Organization, 2009, World Health Statistics 2009.

WHO/UNICEF, 2008. A snapshot of sanitation in Africa. WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.

Yuan C., 1984. The utilization of animal and human wastes in rice production in China, Journal of Organic Matter and Rice, 179-192.

Appendix A

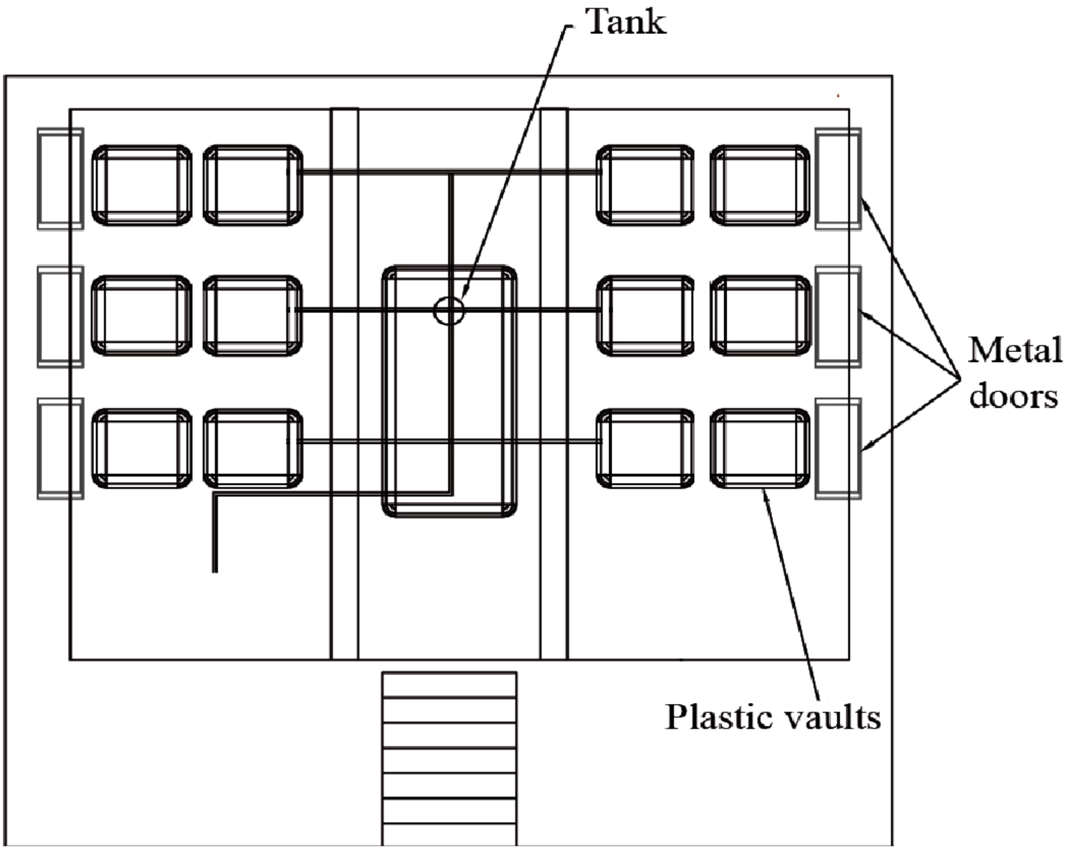

Figure 32: View of the connections to collect the urine and the tanks for the faeces

Appendix B

Table 30: Break down of the estimated cost for upgrading an existing toilet complex to a UDT

Item	Quantity	Unit	Cost (GH¢)
Cement	5	50 kg bag	60
Blocks 5”	200		200
Urinal	1		60
Toilet	6		210
Sand and gravel	1	trips	100
PVC pipe 4”			55
PVC pipe 1 1/4”			30
Plastic tank (3,000 l)	1		500
Miscellaneous			50
Labour			400
		Total cost	**1,665**

Table 31: Break down of the estimated cost for upgrading an existing toilet complex to a UDDT

Item	Quantity	Unit	Cost (GH¢)
Cement	20	50 kg bag	240
Blocks 5”	400		400
Urinal	1		60
Toilet	6		210
Sand and gravel	2	trips	200
PVC pipe 4”			55
PVC pipe 1 1/4”			30
Plastic containers	12		600
Plastic tank (3,000 l)	1		500
Miscellaneous			100
Labour			600
		Total cost[47]	**2,995**

47 The cost could be reduced to GH¢2,605 if metallic or plastic drums from the biodiesel plant are used

Table 32: Break down of the estimated cost of upgrading an existing public urinal to collect urine in an underground container

Item	Quantity	Unit	Cost (GH¢)
Cement	2	50 kg bag	24
Blocks 5”	50		50
PVC pipe 1 1/4”			30
Plastic tank (2,000 l)	1		390
Miscellaneous			30
Labour			250
		Total cost	**774**

Appendix C

Assumptions	
Fuel economy (km/litre)	4
Life span of the equipped truck (years)	10
Life span of the pump (years)	5
Round trip distance Accra- Nsawam (km)	80
Round trip distance Accra- Kade (km)	280

Concept	Cost (GH¢)
Equipped truck	29,000
Price per litre of diesel[48]	1.27
Maintenance cost each 5,000 km[49]	200
Spare parts each 5,000 km	200
Daily salary of the driver	8

Results	Cost (GH¢)
Total cost per round trip Accra-Nsawam	48
Total cost per round trip Accra-Kade	127

48 Average price between September 2008 – September 2009, source: ARS
49 Africa Motors, Ring Road West, Accra

Appendix D

Structure and Properties		Test Methods
Basic Fabric	Nylon 1100 dtex	
Specification	1000d*1000d(18*18)	
Thickness	0.85±0.03mm	DIN53353
Weight By SQM	1100 g / ㎡	DIN EN ISO 2286-2
Tensile Strength	2620 N/ 5cm(Warp)	EN ISO 1421 Meth1
	2380 N/ 5cm (Weft)	
Tear Strength	450 N (Warp)	DIN 53 363
	415 N (Weft)	
Breaking Elongation (%)	24 (Warp)	
	23.5(Weft)	
Temperature Resistance	-30 ℃ to + 70 ℃	DIN EN 1876-2
Peeling Strength	85 N/ 5cm	EN ISO 2411
Colour Fastness (Grade)	7 - 8	DIN54004

Appendix E

Part	Number of pieces	Unit price (US$)	Unit price (GH¢)	Total (GH¢)
Black pipe 2”	11	0.56	0.84	9.24
Black pipe 3”	9	0.69	1.04	9.32
Black pipe 9”	2	1.98	2.97	5.94
Elbow	6	0.76	1.14	6.84
T'	2	1.12	1.68	3.36
4-way	1	4.25	6.38	6.38
Union 2	2	2.96	4.44	8.88
1”-3/4” bushing	2	0.97	1.46	2.91
2” - 1 1/2” bushing	2	2.47	3.71	7.41
1 1/2”to3/4” bushing	2	1.98	2.97	5.94
coupling	2	0.98	1.47	2.94
Brass Valves 3/4” threaded	10	8.79	13.19	131.85
Brass Check Valve	1	8.56	12.84	12.84
Hose and fittings				
Hose barb-3/4” male	10	0.37	0.56	5.55
Hose Clamp	10	0.73	1.1	10.95
Vinyl hose -20 feet roll	2	27.99	41.99	83.97
Quick disconnect fitting (set)	1	12.07	18.11	18.11
Pumps				
Hand Pump	3	20	30	90
5 GPM Clearwater pump	1	30	45	45
Heating				
Heating element - 4400 Watt	1	9.97	14.96	14.96
Wire (10 gauge)	10	0.5	0.75	7.5
15 amp three prong outlet	1	4.98	7.47	7.47
Inline thermometer	1	15	22.5	22.5
Switched outlet	1	18.34	27.51	27.51
Washing	1	19.99	29.99	29.99

Part	Number of pieces	Unit price (US$)	Unit price (GH¢)	Total (GH¢)
Aquarium pump	1	3.69	5.54	5.54
Ailine tubing (25 feet)	1	4	6	6
Stainless 3-way valve	2	1.4	2.1	4.2
Stainless Splitter	4	12.75	19.13	76.5
Air stones				
Measuring and Mixing				
Scale	1	30	45	45
scoop	1	1	1.5	1.5
pitcher (container)	1	2	3	3
funnel	1	1	1.5	1.5
Barrels - polypropylene				
55 gallons-wash 2	6	43	65	390
55 gallons - finished 2	6	43	65	390
15-20 gallons - methoxide 1	3	15	23	70
Safety				
Rubber gloves I	1	3	4.5	4.5
Safety goggles 1	1	6	9	9
Chemical apron 1	1	5	7.5	7.5
Tools				
Teflon tape (10 rolls)	1	6	9	9
Bung Wrench 2	2	7	10.5	21
			Total GH¢	**1,621**