MSc Program
Environmental Technology & International Affairs

Application of cost calculation and comparison methods for resource-oriented sanitation services in Nakuru, Kenya

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 24.06.2011

Affidavit

I, **Maximilian Lang**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Application of cost calculation and comparison methods for resource-oriented sanitation services in Nakuru, Kenya", 72 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 24.06.2011

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Signature

Acknowledgements

I am very grateful to my supervisor Prof. Matthias Zessner for his invaluable advice, guidance and support he offered consistently during the preparation of this thesis.

I would particularly like to thank my co-supervisors Dr. Norbert Weissenbacher and Dr. Günter Langergraber for giving me the opportunity of writing my thesis about ROSA and for their important support and guidance throughout. I am very thankful to Elke Müllegger of EcoSan Club Austria whose help and advice was much needed and appreciated.

Thanks to the CEC staff, in particular to Ms. Starlinger, and to all the students from ETIA 3 for making those two years enjoyable. Special thanks to Vanessa Hamerijckx for her help and constant support.

I am furthermore grateful for my family's support and help throughout my studies.

Finally, but most importantly, I would like to thank Emma Caley for simply too many things to mention.

Contents

Glossary and Abbreviations

Blackwater: "Blackwater is the mixture of urine, faeces and flushwater along with anal cleansing water (if anal cleansing is practiced) and/or dry cleansing material (e.g. toilet paper). Blackwater has all of the pathogens of faeces and all of the nutrients of urine, but diluted in flushwater." (Tilley et al., 2008)

CAPEX: Capital expenditure

CBO: Community based organisation

Compost: "Compost/EcoHumus, description=is the earth-like, brown/black material that is the result of decomposed organic matter. Generally Compost/EcoHumus has been hygienised sufficiently that it can be used safely in agriculture. Because of leaching, some of the nutrients are lost, but the material is still rich in nutrients and organic matter." (Tilley et al., 2008)

EcoSan: Ecological Sanitation

EU: European Union

Excreta: "Excreta, description= "Excreta consists of urine and faeces that is not mixed with any flushing water. Excreta is small in volume, but concentrated in nutrients and pathogens." (Tilley et al., 2008)

Faeces: "Faeces, description=refers to (semi-solid) excrement without urine or water. Each person produces approximately 50 L per year of faecal matter. Of the total nutrients excreted, faeces contain about 10% N, 30% P, 12% K and have 107–109 faecal coliforms /100 mL." (Tilley et al., 2008)

Flushwater: "Flushwater is the water that is used to transport excreta from the User Interface to the next technology. Freshwater, rainwater, recycled greywater, or any combination of the three can be used as a Flushwater source." (Tilley et al., 2008)

Greywater: "Greywater is the total volume of water generated from washing food, clothes and dishware and from bathing. It may contain traces of excreta and therefore will also contain pathogens and excreta. Greywater accounts for approximately 60% of the waste water produced in households with flush toilets. It contains few pathogens and its flow of nitrogen is only 10–20% of that in blackwater." (Tilley et al., 2008)

KES: Kenyan Shilling (at the time of writing, the exchange rate KES:EURO was 126:1)

LAWA: Länderarbeitsgemeinschaft Wasser

MDG: Millennium Development Goals

MEWAREMA: Menengai Waste Recyclers Management

Organic Waste: "Biodegradable organic material that could also be called biomass or green organic waste. Although the other Products [...] contain organics, this term refers to undigested plant material. Organics must be added to some technologies in order for them to function properly (e.g. composting chambers). Organic degradable material can include but is not limited to leaves, grass and market waste." (Tilley et al., 2008)

OPEX: Operational Expenditure

ROSA: Resource-Oriented Sanitation concepts for peri-urban areas in Africa'

UDDT: "A Urine Diverting Dry Toilet is a toilet that operates without water and has a divider so that the user, with little effort can divert the urine away from the faece"s (Tilley et al., 2008).

UN: United Nations

Urine: "Urine, description=is the liquid waste produced by the body to rid itself of urea and other waste Products. In this context, the urine Product refers to pure urine that is not mixed with faeces or water. Depending on diet, human urine collected during one year (ca. 500 L) contains 2–4 kg nitrogen. With the exception of some rare cases, urine is sterile when it leaves the body." (Tilley et al., 2008)

WHO: World Health Organisation

Abstract

Alternative sanitation solutions such as Urine Diverting Dry Toilets are not based on a sewer system. Instead they require special operation and maintenance efforts to stay in working condition. In many cases, especially in urban and peri-urban areas, service providers are required to fulfil those functions against a fee. Such alternative systems, as they are often introduced by development projects, often face problems after the end of the development project in question putting at risk the success of the project. One of the reasons is the difficulty to establish service providers that will continue offering the services once external support has stopped. Due to the poverty of large parts of the populations, the costs of such services must be low while at the same time be sufficiently high for the service provider to continue to offer the services.

Cost calculation and comparison methods help to assess the costs of a project and to find the most cost effective solution for a given context. Applying those methods when establishing operation and maintenance services therefore can be an important step towards their sustainability. This thesis tries to adapt existing methods and to apply them to such a scenario.

1 Introduction

1.1 Background

Many areas in developing countries lack working sanitation systems. Therefore, there is very often no working system of disposing of human excreta in a safe manner. According to the OECD, in the year 2004 worldwide 2.4 bio people were without adequate access to improved sanitation (Evans et al., 2004). About 81% of those 2.4 bio live in rural areas. While in most developed countries state organs supply sanitation to their citizens, this is mostly not the case in developing countries. As such, studies indicate that in African cities 70 - 90% of the households (including nearly all poor households) have to take care of their excreta themselves. Solutions to the problem include building or purchasing own latrines or sceptic tanks (Collignon and Vézina, 2000). In many cases, the solutions found by the population do not fully solve the problem. The unsafe disposal as a result contaminates the very water used by humans for drinking, cooking and washing. In many developing areas, only few people have easy access to sufficiently safe water supplies. Due to this situation, many people are constantly in contact with pathogens coming from the excreta and suffer from related illnesses. Lack of sanitation is one of the main reasons for widespread diarrhoea in Africa, which is dangerous especially for children and the elderly. The WHO attributes approximately 88% of diarrhoeal diseas to unsafe water supply, inadequate sanitation and hygiene (WHO, 2004).

To show the magnitude of the problem, according to the the WHO's 2003 World Health Report, in 2002 1.6 mio children under the age of 5 died because of diarrhoea alone. This represented 15% of all child deaths in developing countries (WHO, 2003). Despite still being at a high level, mortality from diarrhoea for children has been decreasing significantly. However, morbidity levels for all age groups, particularly for children, do not show a decreasing trend of similar proportions and thus remain an important problem (Jamison et al., 2006). Apart from the evident negative effects on the well being and the quality of life, the multitude of health problems also have negative economic impacts for those who, due to their illness, cannot work. The WHO estimates that for every case of diarrhoea in an adult, 2 working days are lost (Hutton and Haller, 2004). Therefore, in many developing countries this is a serious burden on society and the countries' economies, endangering the livelihood of important parts of the populations . It is estimated that in Kenya, the consequences of preventable diarrhoea cost 10% of the yearly national health budget (Onyango et al., 2009).

As an example, according to a 2007 report, in Kitgum, Uganda, 89% of the population obtains its water supplies from boreholes and 2% from shallow wells. Water there is usually consumed without boiling, even though chlorination tablets are supplied. As a result, 59,9 % of the households participating in the survey people have suffered from waterborne diseases within the last year, of which 74% is attributed to cholera (ROSA Project, 2007).

For the above mentioned reasons, it is evident that a lack of sanitation and safe water supply is a huge problem. In the year 2000, 192 UN member countries and 23 international organisations agreed on a global action plan to achieve 8 Millennium Development Goals (MDGs) to be reached until 2015 with a view to improving social and economic conditions in the world's poorest countries. "Ensuring environmental sustainability" is goal 7. It addresses the sanitation and water supply problems by including the subgoal 7C: "Halving, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation". Taking into account population growth, this means that by 2015 at least 1.47 billion people would have to gain access to basic sanitation (Evans et al., 2004). According to a 2004 WHO study, if the Millennium Development Goal 7C was attaint by 2015, world wide 3.2 bio working days would be gained as well as 272,482 days for children to attend school (Hutton and Haller, 2004). As far as the MDGs are concerned, for investments in this area in sub-Saharan Africa, a cost-benefit ratio of 5.7 is expected for meeting the water and sanitation goals. For sub-Saharan Africa, this would result in benefits of on average US$ 17.5 per capita per year and hence making it the region that would profit most from achieving the water and sanitation goals (Hutton et al., 2007).

1.2 Problem Definition

In many developing countries attempts are made to introduce alternative sanitation systems to solve the sanitation problem without the need of building a sewage network. In many cases such systems rely on the containment and subsequent collection and treatment of the excreta. One of those approaches is *resource-oriented sanitation* which aims to supply safe sanitation and to recover the nutrients from the excreta for agricultural use. However, for such infrastructure to work, it is essential for it to be accompanied by operation and maintenance efforts such as the collection and treatment (Sohail et al., 2001; Brikké, F. and Brodero, M., 2001). Without regular servicing such as emptying, such infrastructure will not only stop working and but will no longer offer any advantages. Instead there is a high probability for it to become a health hazard itself.

Operation and maintenance is a problem in rural as well as in peri-urban or urban areas. Depending on the context, different approaches are possible. In rural areas, owners of resource-oriented sanitation infrastructure might be more likely to be able to treat and finally use the sanitised product for their own agricultural activities. However, in urban and peri-urban areas with a higher population density, in most cases this is not possible.

Therefore, in many cases a different and somewhat more centralised approach might be required to solve the operation and maintenance problem. One possibility is to have an external service provider that will collect and treat the human waste for a designated fee (Sohail et al., 2001). Even in low-income areas, people seem to be willing to pay for such services. There is therefore a potential for entrepreneurs or community based organisations to fulfil those functions, while at the same time earning money by doing so (Muchiri and Mutua, 2011). This aspect is especially important with a view to sustainability of the infrastructure. Only if real incentives exist, such services can outlive the development project that in most cases was responsible for its introduction. Before providing such services, it is however essential to be able to estimate the costs, both the investment costs as well as the running costs. This step is important to judge how much income must be generated for the service to be sustainable or even profitable. Such an estimate allows for the comparison of costs between different options and to find the most cost effective solution for a given context.

1.3 Research questions of this thesis

Unfortunately, there is a general lack of data regarding the operation efforts and costs involved in offering such services in low-income areas. The goal of this work is to evaluate existing cost calculation procedures, to adapt them to be used for estimating the costs involved in such treatment and collection services and to apply the cost calculation procedure in a given scenario.

To do so, this thesis will try to analyse the processes and costs involved in delivering sanitation services in Nakuru, Kenya. Nakuru was one of the pilot cities of the project "Resource-Oriented Sanitation concepts for peri-urban areas in Africa" (ROSA), carried out from October 2006 to March 2010 with the aim of introducing sustainable sanitation concepts in peri-urban areas in Africa. Based on this, an attempt will be made to adapt existing cost calculation and comparison methods to be suitable for the local context. This should result in general guidelines on how to proceed to estimate the costs of such a service. Furthermore, it should indicate how changes in different variables would have an effect on the costs of such a businesses considering different options of delivering the services. Former studies, namely the thesis "Profitability of a community-based resources-oriented human waste management system in Nakuru, Kenya" by Grambauer, F. (2010) and the thesis "Operation and Maintenance of Resource-Oriented Sanitation Systems in Peri-Urban Areas" by Bräustetter, A. (2007), have already researched and analysed the local business MEWAREMA (Menengai Waste Recyclers Management), a community based organisation in Nakuru delivering collection and treatment services and evaluated its profitability.

This thesis will focus on the costs involved, the main research questions are the following:

- **Question 1:** What method can be applied to calculate and compare the costs of delivering collection and treatment services for human excreta in the local context of Nakuru, Kenya?
- **Question 2:** In the case of Nakuru, what seems to be the most cost effective transport solution for MEWAREMA?
- **Question 3:** Sensitivity Analysis: How would certain changes in parameters influence the results?
- **Question 4:** How reliably can such a calculation estimate the costs and what are the main problems restricting accuracy?

1.4 Structure of the thesis

Chapter 2 will feature a literature review to explain the sanitation problems in developing countries. It will give an overview of the concepts used and will introduce the local context, the ROSA Project and the infrastructure in question and cost calculation methodology. In the third chapter, existing cost calculation methods for sanitation investments will be reviewed. After this step, the services as provided by MEWAREMA will be explained and the costs and efforts that are taken into consideration will be listed and analysed as far as data is available or reasonable assumptions can be made. Background data for alternative options will be added as well for the comparison of options that will follow. Once both the methods as well as the background is explained, the results will be applied to compare several transport options and to find the most cost effective one in the given context. Overall, three scenarios will be calculated. Those calculations will include both different options in terms of delivering the service as well as a sensitivity analysis regarding certain variables of interest. In chapter 4, the results of the calculations will be discussed along with possible problems and implications. The limits of the results of the calculations, in terms of accuracy and reliability, will be analysed. Furthermore suggestions will be given on how the problems could be solved and the results improved. The conclusion will summarise the answers to the research questions and the results of this thesis.

2 State of the Art and Literature Review

2.1 Excreta

2.1.1 Faeces

Human excreta contain many pathogens that are dangerous for human health such as viruses, bacteria, protozoa and worms. Furthermore, insects such as mosquitoes, that in many regions can spread diseases such as malaria, may use excreta as a breeding ground (Feachem, 1983). Managing human excreta in a way that will not endanger human health or the environment is therefore essential. However, as shown in Table 1, faeces also contain an important amount of nutrients that were contained in the food. Therefore, if the faeces have been sanitised correctly, those nutrients can be an important resource for agriculture.

The output of faeces by a humans differs a lot between cultures and varying diets. For instance, a vegetarian diet will result in a higher volume of solid excrements. In 1983, a World Bank Study concluded that "Individual wet faecal weights vary from under 20 grams per day to 1.5 kilograms per day" (Feachem, 1983). For Kenya other sources name a daily wet output of up to 520 grams (Jönsson et al., 2004). Water content generally increases with the weight of dry faeces produced. For an average production of wet faeces of 100 - 150 grams per person per day according to the same study, the water content is about 75%, while in a community with an average of 500 grams per person a day it might be up to 90%. Europeans and North Americans generally produce excreta in the range between 100 and 200 grams of wet faeces per day. Citizens of developing countries, whose diet usually contains a higher content of vegetables, produce between 130 grams and 520 grams. Furthermore, children and seniors also have different eating habits and therefore have a higher water content in their faeces. In rural areas, generally more vegetables are eaten than in urban areas resulting in differences in the faeces production. Taking into consideration the various variables, the same WHO study concludes that for developing countries, it is advisable for calculations to estimate about 350 grams of wet faeces in rural areas, and 250 grams of wet faeces in urban areas (Feachem, 1983).

2.1.2 Urine

Urine production depends on various factors such as the amount of liquid ingested, the climate and resulting transpiration. For coherence with the units used for faeces, as with the estimate of the daily production of faeces, the same 1983 World Bank Study

(Feachem, 1983) suggests an average urine production between 1.0 litres and 1.3 litres per day. For developing areas, the study suggests assuming a daily production of 1.2 litres per person.

As shown in Table 1, urine is very rich in nutrients, especially in nitrogen. It can therefore be particularly valuable if the nutrients in human excreta are to be recovered and reused for agricultural purposes, as ideally foreseen by the concept of sustainable sanitation (Drangert, 1998). Urine contains relatively few pathogens, namely viruses and protozoa. If not mixed with water or other substances, urine is stable and can be stored without any concerns for longer periods of time. It is estimated that in closed storage at a temperature of 20°C, protozoa die of within one month of storage and all the viruses after a maximum storage of six months (WHO, 2006). At this point urine should be pathogen free and can be used for all fertiliser purposes (Schönning, 2002).

As far as micropollutants in urine due to the intake of pharmaceuticals are concerned, this is a different matter. Micropollutants are often not reduced by storage and might be taken up by plants. It is however suggested that in developing regions, where the use of pharmaceuticals is lower and the presence of other pollutants is often much more severe, this is not a primary concern (Winker, 2010).

The actual production of urine and faeces per person will not play a major role in the examples, it is however an important factors to be able to estimate the amount of services required. From a ROSA Project report from Nakuru, it can be derived that, if it is assumed that 1.2 litres of urine is produced per person per day, then at this point in households ca 60% of the urine output will end up in the Urine Diverting Dry Toilets (UDDT) of the residential plots (Muchiri and Mutua, 2010). The difference between the amount of urine discharged each day by a person and the amount captured by the UDDT is due to the fact that the UDDT will not be used at all times by a all members of the household. Instead, with a relatively small number of UDDTs installed as it is still the case on the project locations, it is safe to assume that a part of the urine will end up differently. The amount of urine introduced into the UDDT system per person per day is thus theoretically a variable factor.

Nutrients in kilograms / capita / year				
Nutrient	In Urine (500 l per year)	In Faeces (50 kg per year)	Total	Required for 250 kg of cereals*
Nitrogen (N)	4.0	0.5	4.5	5.6
Phosphorous (P)	0.4	0.2	0.6	0.7
Potassium (K)	0.9	0.3	1.2	1.2

Table 1: Nutrient content in excreta per year after Drangert, 1998
* yearly food equivalent for one person

2.2 Sanitation approaches

2.2.1 Sewage systems or conventional sanitation

The conventional waterborne sewage collection and disposal system that is used in most developed areas has solved the hygiene and sanitation problem and has dramatically increased hygiene, especially in urban areas. Today it is by far the predominant for example in Europe (Jewitt, 2011). Since the 19th century, this system has seen major improvements and it has been more and more turned into a centralised system. The system has evolved mainly in regards to achieving hygienic improvements and in the last decades to minimise pollution of water bodies (DWA, 2008). In the logic of having to dispose of the excreta to preserve hygiene, in such systems the excreta are more or less directly transported using water as medium. During this process, not only is the Greywater, for example from households, used to transport the faeces and the urine. In developed areas, usually large amounts of water with drinking quality are used as well for the flushing mechanism. On average about 15,000 litres per person each year are used (Simpson-Hébert and Winblad, 2004). Without subsequent treatment, this results in the initial harming substances being diluted into a much larger volume of Blackwater. If this waste water is not treated, it poses an important thread for the water bodies downstream. In most developed areas and very few developing areas, today the waste water is treated in a sewage treatment plant where N and P can be recovered and pathogens are removed, minimising the negative impacts when the water is released (DWA, 2008).

Nowadays, the goals in creating a sanitation system go further than hygiene alone and factors such as environmental protection or closing the nutrient cycle by recovering and reusing the nutrients gain new momentum (Bracken et al., 2007). However, experience has shown that to do so, a simple end-of-pipe approach may not always be effective enough. Instead, measures taken at the various steps of the sanitation system can improve efficiency. Alternative sanitation approaches such as ecological sanitation / sustainable sanitation try to do that. The ideas behind concepts such as sustainable sanitation are not new and had been practiced not only in Europe but especially by the Chinese for many centuries or even thousands of years. However, with the introduction of sewage based sanitation, availability of industrially produced fertilisers and a lifestyle that for most people does not include agricultural activities, the knowledge about the usefulness of human excreta was largely forgotten or at least ignored (Bracken et al., 2007). In a world, where the requirements for a sanitation system differ largely between regions in terms such as population, water availability and budget, there is no single system that can satisfy all prerequisites. Alternative systems should therefore be taken into consideration if the goal is to supply the benefits of sanitation to the masses who are not covered as seen in Table 2.

World Coverage of Water Supply and Sanitation Supply by Area		
Area:	Water supply coverage	Sanitation supply coverage
Africa:	62%	60%
Asia:	81%	48%
Latin Am. & Caribbean:	85%	78%
Oceania:	88%	93%
Europe:	96%	92%
North America:	100%	100%

Table 2: Overview of water supply soverage and sanitation supply coverage according to WHO / UNICEF (2000)

Budget plays an important role when it comes to creating sanitation infrastructure. In Germany and Austria, the existing sanitation systems are largely a responsibility of public bodies. Most systems were created in the past, paid for by taxes and built to serve the public for very long time spans (DWA, 2008). In such a context, important investments in a highly centralised waterborne sewage system are affordable investments. In most developing countries it is however simply not feasible to invest the amounts of money that would be required to supply such a system to large parts of the population (Simpson-Hébert and Winblad, 2004). Furthermore, as mentioned already and described further on, there are also other arguments than only costs that may make alternative systems viable options in certain contexts.

For a long time, the recovery of contents from the waste water had not played a big role in the conventional sewage system. Its purpose was simply to get rid of the harming substances (Bracken et al., 2007). Only with the growing problems of pollution and eutrophication of water bodies in the 20^{th} century (Conley et al., 2009) due to urbanisation, industrialisation and the introduction of sewage systems more or less everywhere, the recovery of nutrients from the waste water before releasing it became an issue (Schindler, 2006). Since the 1950s and with the introduction of stricter regulations, the removal systems have been constantly improved. Nowadays they manage to eliminate or at least control the carbon, nitrogen and phosphorus content in the water, leaving the sewage plants, resulting in once again largely improved quality of water bodies in recent decades (Nixon et al., 2000).

But it is not only the avoidance of water pollution and eutrophication that demand the uncontrolled release of nutrients into the environment. Already today, fertilisers are required to keep global agriculture production at levels that can provide food for the world's population. As the population keeps growing, it must be assured that sufficient fertiliser will also be available in the future so that agricultural production can match the growing demands (Ruttan, 2002). However just as with other goods, the current consumption of fertilisers is not sustainable. While Nitrogen is abundant in the atmosphere, rendering it useful for most plants as NH_3 using the Haber-Bosch process is energy intensive and will become more expensive as energy prices rise. According to studies, fertiliser production consumes currently approximately 1.2 % of the world's energy (about 0.9% in Western Europe) and is responsible for approximately 1.4% of green house gas emissions (about 1.8 % in Western Europe) (Kongshaug, 1998).

As for phosphorus the situation is even more serious, as there are only limited resources available (Steen, 1998) and recovery of phosphorus should be improved (Liu et al., 2008). Production costs are already increasing and it is expected that those conventional reserves might only last another 50 - 100 years with "Peak Phosphorus" being possibly reached already in 2033 (Cordell et al., 2009). There are thus many reasons why different ways of recovering the nutrients from human excreta should be considered.

2.2.2 Ecological Sanitation (ecosan)

According to (Simpson-Hébert and Winblad, 2004), ecological sanitation is based on three fundamental principles:

- Preventing pollution rather than attempting to control it after we pollute
- Sanitising the urine and the faeces
- Using the safe products for agricultural purposes

The ecosan approach tries to move away from the sometimes called "flush-and-discharge principle" of most waterborne sewage systems. Instead of mixing and diluting faeces and urine with water into one single stream, the first principle is not to dilute the excreta. This way, the large volume of Greywater that occurs in households, which has a low pathogen content (Tilley et al., 2008) is not contaminated with the pathogens from the human excreta, easier to handle and much less dangerous.

Unlike most conventional sewage systems, the ecosan approach is in favour of more modular systems which may, but do not have to, contain centralised elements. In conventional systems, usually all the excreta are delivered to and treated by one or very few big facilities. Ecological sanitation concepts however scale differently and often do not require high investments and hence can be implemented even at small scale (Lechner and Langergraber, 2004). Ecological sanitation principles can be implemented either as completely individual solution where owners treat and reuse their own excreta without external help for private use or as some sort of more centralised system with one big collection and treatment service similar to that of household waste, or in many steps in between (Esrey et al., 2001). It is important to remember that a toilet is not the only part of a sanitation system, instead it is just the user interface. Further in the chain after the toilet there are the stages of collection, transport, treatment and ideally reuse. For each of the steps in the chain there are different choices, however not all are compatible with each other (Netherlands Water Partnership, 2009).

When it comes to the recovery of nutrients, the ecosan approach tries to establish a cycle where excreta are collected, treated and eventually reused as fertiliser to grow food as represented in Figure 1. As minimising the risks coming from excreta is an essential aspect of the ecosan approach, sanitation has to occur before reusing the waste as fertiliser in agriculture, this is especially important for the faeces part of the excreta (Esrey et al., 2001). Hence, the ecosan approach is fully aware of the dangers of excreta but still recognises the value of its contents and wants to re-establish the natural cycle while conventional sanitation approaches usually see more of a linear flow (Simpson-Hébert and Winblad, 2004).

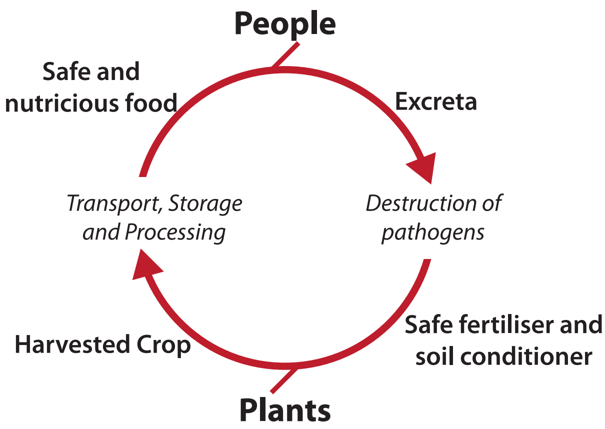

Figure 1: The ecosan ecosystem loop, adapted from Esrey et al. (2001)

But ecological sanitation is not only about sanitation, it is also about hygiene practices in general. Other than the lack of sanitation infrastructure in most areas in developing countries, widespread false beliefs and insufficient knowledge about hygiene and the negative impacts of human and animal excreta are a major problem (Ilesanmi, 2006). Often open defecation of animals and children is not seen as something harmful and thus accepted (ROSA Project, 2007). Other common problems are for example a lack of separation between food preparation and other activities, both in terms of space as well as in terms of habit. This results in a higher chance of food getting in contact with harmful pathogens (Simpson-Hébert and Winblad, 2004).

According to Esrey et al. (1991), a seemingly simple measure such as hand washing can reduce the occurrence of diarrhoeal diseases by 33%. The same source states that improved water quality can lead to a decrease of diarrhoeal diseases of 15% and improved sanitation even of 36%. Therefore, is is clear that the cycle of faecal-oral diseases needs to be broken via various means as illustrated in Figure 2. The solution to solving the problem must therefore lie in both the introduction of technology as well as in changes of everyday habits of the population at large. This is why the ecosan approach also stresses the importance of education and awareness creation about general sanitation principles that can improve hygiene significantly (Simpson-Hébert and Winblad, 2004): Consistent use of toilets to keep faeces out of the environment; Hand washing after using the toilet, after cleaning up the faeces of children or helping children to use the toilet, and before food preparation or feeding children; Measures to keep drinking water clean; Hygienic food preparation and storage and reheating.

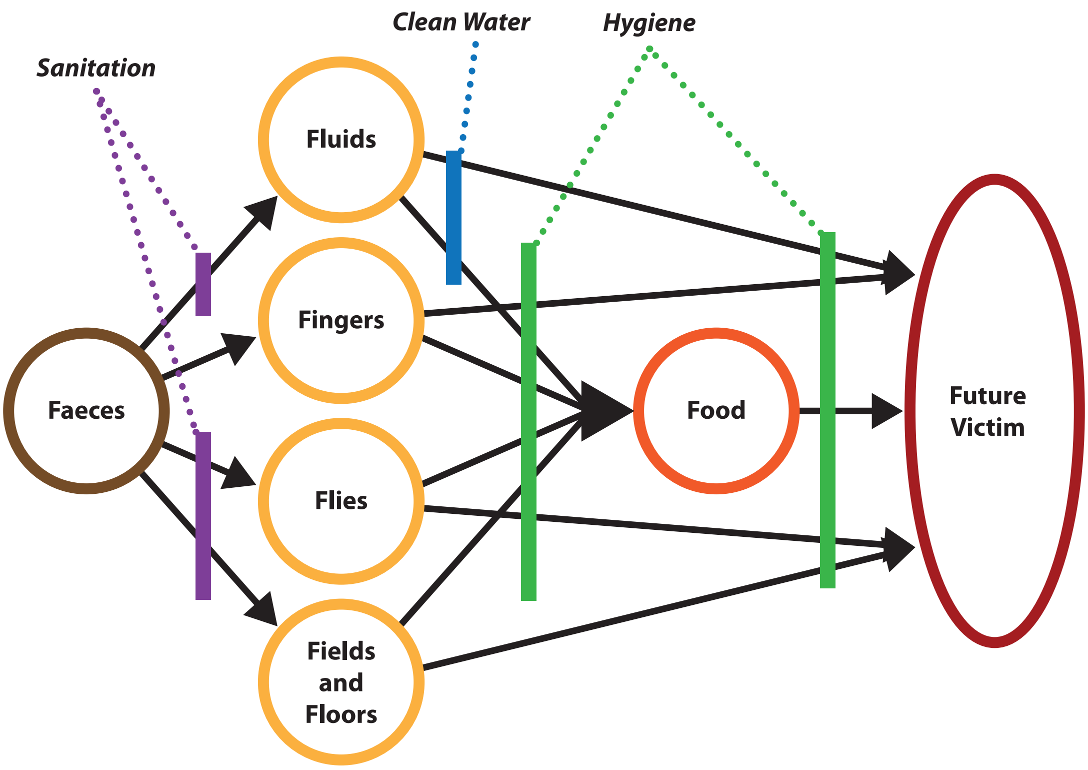

Figure 2: F-Diagramme on the distribution of pathogens (after Marcotullio and McGranahan, 2007)

2.2.3 Urine Diverting Dry Toilet (UDDT)

There are various variants of alternative toilet systems that handle excreta in a safe manner. Unlike in flush toilets, UDDTs are two vault systems where faeces and urine are collected separately from each other without mixing, as illustrated in Figure 3, and that function without using water. A divider ensures that urine is collected and drained in the front part of the toilet with minimal user efforts. The back part features a relatively large hole into which the faeces will fall. The separation of urine and faeces must be as complete as possible throughout the process. Faeces falling into the front part would clog the outlet and contaminate the urine. Likewise, urine that gets mixed with faeces would disturb the drying and sanitation process. When cleaning the bowl, no water should enter the faeces vault. For cleaning, a damp cloth should be used instead to wipe the seat and the inside of the bowls instead of water. Because of those precautions that must be taken, UDDTs are often more cumbersome to clean than most other toilets, unless some method for removing the bowl from the vault is foreseen in the design of the toilet (Tilley et al., 2008).

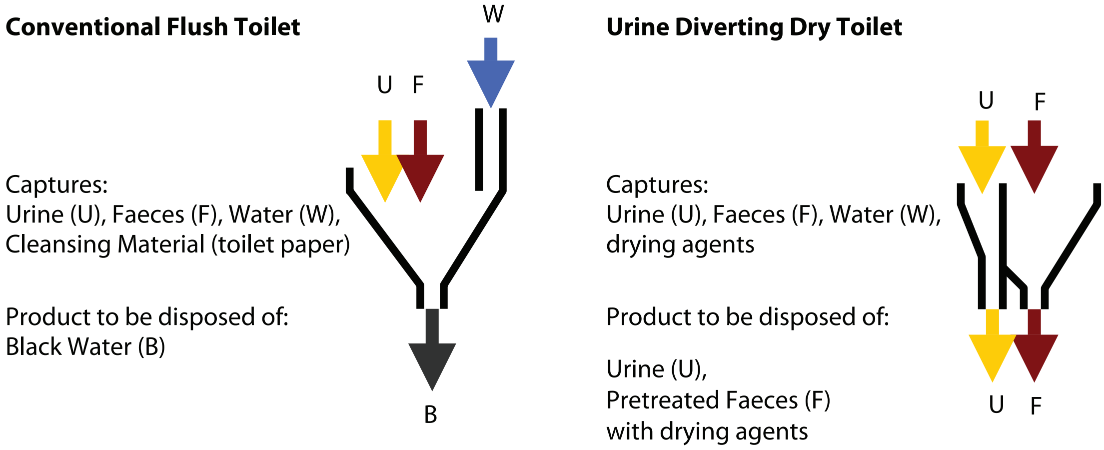

Figure 3: Comparison of flows between conventional flush toilet and UDDT (DWA, 2008)

Only if the UDDT is used correctly, thus kept clean and all the rules regarding operation and maintenance as well as storage and handling of the excreta are respected, it is compatible with ecological sanitation principles (Müllegger and Freiberger, 2010). UDDTs exist in different variants and price ranges, as pedestal or squatting pan, made from concrete, plastics or ceramics. Therefore many designs can easily be produced locally (Ayele Shewa et al., 2010) as the design is both simple and can be adjusted to local preferences. Special designs with a third outlet allowing for wet anal cleansing exist, even though they are not very common (Tilley et al., 2008). Such special designs are however a prerequisite for the usability of UDDTs in some cultures. If anal cleansing is foreseen, it is also essential that the three products remain distinct and do not mix.

To ensure acceptance and correct use, users of UDDTs usually require training and guidance to avoid mistakes that will endanger the proper functioning of the device. This is especially difficult for guests who are not familiar with UDDTs. As such, a common problem for men's toilets is for example the misuse of the faeces fault as urinal (Tilley et al., 2008).

For men's bathrooms it is advantageous to use urinals to collect just the urine such as illustrated in Figure 4. Either way, faeces and ideally also urine are collected in some sort of container and not released into the environment. Therefore UDDTs are usually somewhat elevated so the containers are easily accessible. The containers for the faeces must be alternated when one container is full. Because of this necessity, 2 or better 3 containers in total should be available below the toilet: one that is collecting the contents at the moment, one where pre-treatment currently occurs and one that is empty and can replace the current container when it is full. As this system does not require digging holes, according to the Tilley et al. (2008), it "is especially appropriate for rocky areas where digging is difficult, where there is a high groundwater table, or in water-scarce regions". Cleansing materials used should be collected and be disposed of separately.

To enhance the hygienisation process of the faeces in a UDDT, pre-treatment is required. It consists of adding ash, lime or dry earth directly after defecation into the hole onto the faeces. For this, there is generally a container with such materials as well as a shovel available next to the toilet. Adding those materials with a basic character after usage to the faeces vault plays an important role in drying the faeces and enhancing the pH to a value of about 9. This pre-treatment of the faeces in the UDDT decreases the water content and thus volume and weight. Furthermore the pathogen content is reduced and the general consistency for further handling is improved. Pathogen reduction in such a context can occur due to general animosity and competition between organisms for available nutrients and a hostile environment caused by varying pH values, temperature and moisture (Rose, 1999). By covering the faeces, odours are reduced and also insects such as flies, that could distribute the pathogens, cannot reach the faeces. It is important that the containers storing the faeces are kept in a very dry environment. Factors such as climate also have an impact on the drying and thus hygenisation of the faeces collected (Tilley et al., 2008). Simpson-Hébert and Winblad (2004) suggest that in most climates, a storing period of 6 to 12 months should be sufficient to kill most pathogenic organisms. Still even after this period, the pre-treated excreta need to be handled with care to prevent the workers from health risks, which is why wearing some protective clothes is essential.

Figure 4: UDDT and Urinal, Hilton Estate, Nakuru (Photo by Steffen Blume, http://www.flickr.com/photos/gtzecosan/3449000739/)

As a container for primary collection of faeces within the UDDT, there are various options. The containers used may vary significantly in volume, form and material. One variety used within the ROSA project are baskets made of local materials which are easy to handle and come at low costs (Senzia et al., 2009). For transport, it would be possible to either empty the smaller containers at the client's houses into a bigger container on the cart or to take the whole container as it is and replace it with an empty container. In this case, the use of baskets may proof to be a good solution.

If urine is collected, it can be stored in various ways such as for example in big tanks or in smaller but removable in jerry cans (Bräustetter, 2007). As the jerry cans can be closed tightly and urine is stable when stored, there would however be no necessity for a weekly service emptying the cans. The full cans could simply be exchanged with empty ones and store the filled can for a given period of time. The service operator then again could either empty the contents of the jerry cans into a portable tank or take the full cans in exchange for empty cans. The latter option would have the advantage of not requiring specialised equipment for transporting as transporting the closed cans is easy and convenient.

The general advantages of UDDT for its users, if used and maintained according to the guidelines, are safety due to improved hygiene, comfort by avoiding odours and flies and the possibility to recover the nutrients for agricultural use. Its disadvantage are the requirements for operation and maintenance as well as for training measures to avoid the likelihood of misuse and resulting problems.

2.3 The ROSA Project

ROSA stands for "Resource-Oriented Sanitation concepts for peri-urban areas in Africa" and was a specific target research project funded within the EU 6th Framework Programme Sub-priority "Global Change and Ecosystem" with a view to achieving sustainable sanitation and the UN Millennium Development Goals. The project lasted for a period of 42 months from October 2006 to March 2010 and had a total budget of €2.9 Mio.

The project objectives were (Langergraber, 2010):

- To add to the current efforts for promoting resource-oriented sanitation concepts as a route to sustainable sanitation and to fulfil the UN Millennium Development Goals
- To research the gaps for the implementation of resource-oriented sanitation concepts in peri-urban areas
- To develop a generally applicable adaptable framework for the development of participatory Strategic Sanitation and Waste Plans (SSWPs)
- To implement resource-oriented sanitation concepts in four pilot cities in East Africa

(Arba Minch, Ethiopia; Nakuru, Kenya; Arusha, Tanzania; and Kitgum, Uganda - see Figure 5)

The four pilot cities share similar characteristics and problems. Their populations are poor, of similar size with relatively high population growth and generally not provided with sufficient sanitation and waste management. Furthermore, they all are situated in dry regions resulting in a lack of water.

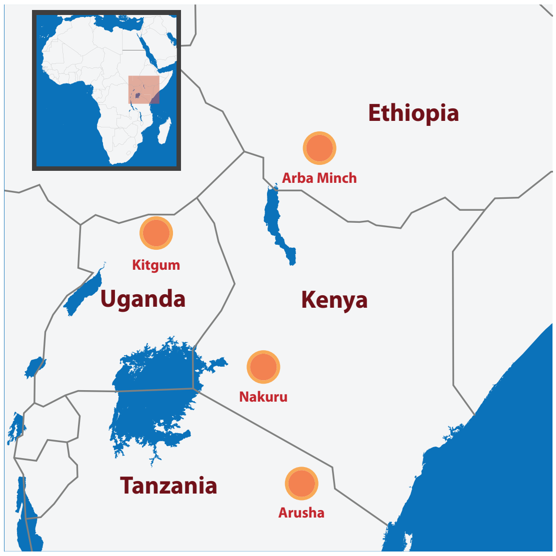

Figure 5: Map with ROSA pilot cities in Eastern Africa

The project was implemented by a consortium of international and local partners in the four different areas in Eastern Africa. The implementation of the ROSA pilot cities consisted of an assessment of the current situation, the introduction of the ROSA concept if possible with the support of the local population and the introduction of different possibilities of sustainable sanitation infrastructure. ROSA was promoted in the stakeholder community, meetings and discussions were organised to ensure a wide support of the project.

Broad support was very important as the project itself was restricted to only a few years, but the solutions introduced were supposed to outlast the project and bring sustainable improvements to the communities, something that could only be achieved with actual support of the stakeholders. One opf the infrastructure options introduced, and which this thesis is concentrating on, are UDDTs. Once a consensus had been reached, UDDTs were constructed as well as some infrastructure for the treatment of the human excreta installed. Finally the users received training in the operation and maintenance of the facilities and the management of the excreta disposal. To ensure a success of the project after the end of the project, this last step was especially important (Muchiri and Mutua, 2010).

2.3.1 A brief overview of ROSA pilot city Nakuru, Kenya

Nakuru is the pilot city of ROSA which will be the basis for the data used in this work. In Nakuru, the community based organisation MEWAREMA is supposed to collect and treat the excreta from mostly privately owned UDDTs. MEWAREMA was already before ROSA collecting organic waste from the local dumpsite for composting. The compost was then sold to NAWACOM, an organic fertiliser cooperation (Bräustetter, 2007). By offering the collection and treatment services for the UDDTs, the initial business model was thus not entirely changed but rather extended (Grambauer, 2010). Prior analysis of ROSA in Nakuru and MEWAREMA exist, in particular by Bräustetter (2007) and Grambauer (2010). Those whose works were important sources of information for this thesis regarding the processes, the quantities and local prices.

Nakuru has an estimated population of 500,000 which is growing at a rate of 7%. Lack of sanitation is a major problem, only 19% of the population in the area has access to water borne sanitation. The biggest part of the population uses inadequate sanitation systems. The effects are various hygienic problems like pollution of the ground water and the resulting negative impacts on human health and the environment. In Nakuru, ROSA has installed UDDTs in two poor, high density settlement areas: London and Hilton. One of the UDDTs was installed at a secondary school (Crater View) where the teachers and 215 students participate themselves in the operation and maintenance of the facility. The excreta is treated for producing fertiliser and used by the school for its own agriculture activities. The other UDDTs were placed in a church and nursery school (ca 25 children) and a residential plot (28 private households à 3 persons), ideally served by third parties to maintain and empty the toilets and treat the human waste (Muchiri and Mutua, 2010). MEWAREMA is supposed to serve ca 24 mostly privately owned UDDTs in the area (Grambauer, 2010).

2.4 Definition of Cost Calculation Procedures

When planning to create a business or to make an investment in general, it is essential to know the costs that are to be expected, to establish the amount of funds required to start and maintain the services. This includes a reliable estimate of the investment costs and the running costs that occur during operation. Only when the costs are known, a financing scheme can be created and the costs can be compared against the projected incomes.

For this work, the "German Guidelines for dynamic cost comparison calculations of the Länderarbeitsgemeinschaft Wasser" (Länderarbeitsgemeinschaft Wasser, 2004) will be used as an example of a cost comparison method (further referred to as "LAWA guidelines"). Those guidelines are used for estimating the costs of sanitation related investments and to compare the costs of different options over a certain time span. Of course, the LAWA guidelines target very different scales than it is the case for investments such as for MEWAREMA in Nakuru. The LAWA guidelines target mainly expensive and very long term, mostly public infrastructure investments serving thousands of households over many decades as they are typical in Germany or Austria (Länderarbeitsgemeinschaft Wasser, 2004).

Furthermore, a cost comparison procedure such as the LAWA guidelines can help to assess different investment options. To do so, the costs of different ways of achieving the same or very similar results are compared. Ideally this is done by not only looking at an investment's immediate costs but at the costs that the investment will bring with itself over its lifetime or a differently defined time span (Länderarbeitsgemeinschaft Wasser, 2004). Looking at those overall costs of an investment, this approach tries to give financial planning reliability. This is an important feature, not only but especially when the object is financed with a loan. Also, doing so facilitates the comparison between two or more different solutions with the same outcome from a financial point of view. Cost calculation procedures as the LAWA guidelines do however not take into consideration non-monetary factors that might play a role in the choice of the investment. As a consequence, the result of the cost comparison method only reflects relative superiority of one investment over another, namely from the financial point of view. It does not reflect absolute superiority as it cannot take into consideration and value all aspects.

3 Material and Methods

3.1 Cost Calculation Procedure

Unlike the LAWA guidelines, this thesis targets micro and small scale businesses or community based organisations that will only serve a relatively small user base of installed UDDTs, at least in the beginning. Such scenarios require investments seemingly negligible in comparison to those of European sewage infrastructure. Furthermore, the time scales considered will be much shorter. The capacity of the services will be much more variable and depending on actual demand than those of conventional sewage systems. However, while the scales may differ, the approach and methodology used by the LAWA guidelines are not inherent to such big infrastructure investments, instead they are general principles. Using the LAWA guidelines as an example, this thesis will try to adapt those principles with a view to using them to estimate the costs of services collecting and treating human excreta, for example from UDDTs, in a developing context.

As described, a main function of using cost comparison methods is to compare the costs of different options against each other. To be effective, the options considered in a cost calculation comparison must fulfil three prerequisites (Länderarbeitsgemeinschaft Wasser, 2004):

- They all fulfil certain normative goals which are defined by the project
- They achieve the same value in terms of service rendered
- Non-monetary effects are inexistent or comparable

A cost comparison calculation can only bring optimal results if beforehand important decisions have been discussed and an amount of data has been collected. In particular this means the identification of the problem, of the goal, of the various alternatives taken into consideration to solve the problem and the compilation of sufficient information on those alternatives to make a comparison possible. This also includes estimates over the development of the demand of the service in the future.

The procedure should follow the schema as indicated in Figure 6 and is divided into two main stages. The preliminary stage (Stage I) prepares the cost calculation. Once the preliminary of the process is completed, the cost calculation procedure should follow the steps as described in Stage II: identification of the costs, application of financial mathematical methods, comparison of costs, sensitivity analysis and finding of critical values and finally an overall evaluation and interpretation of the results.

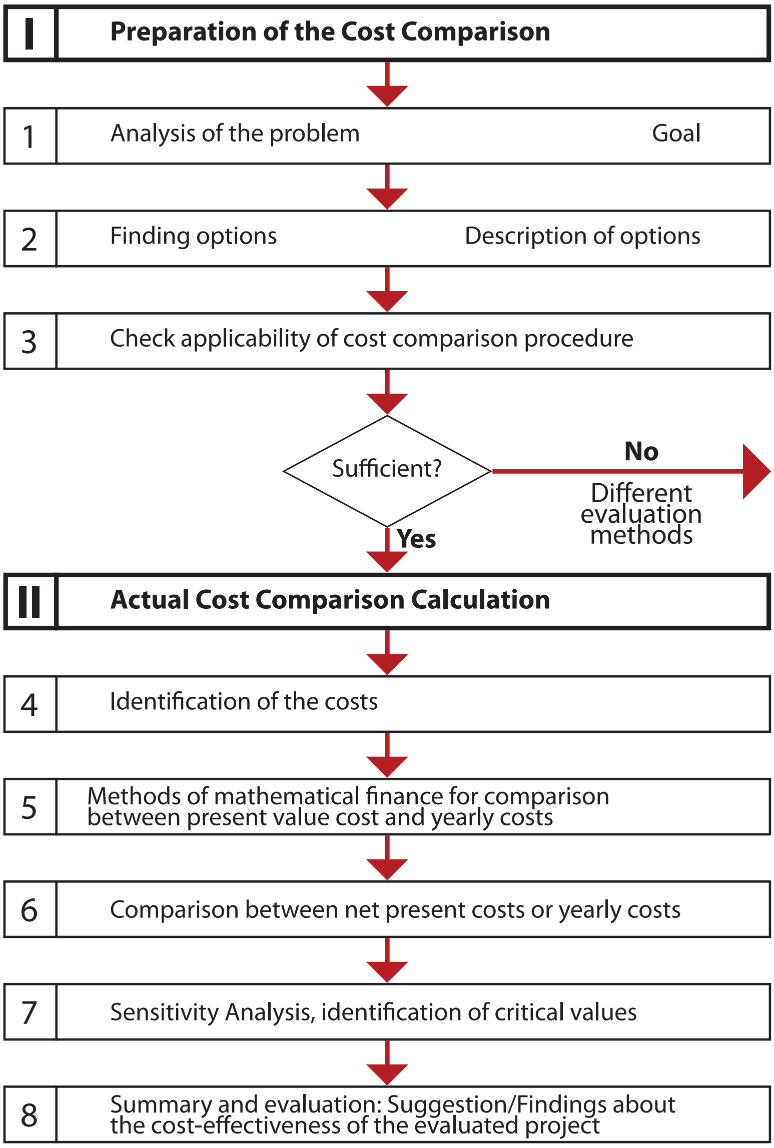

Figure 6: Cost calculation procedure decision making process, according to LAWA Guidelines (after Länderarbeitsgemeinschaft Wasser, 2004)

Later in this work, those guidelines will be applied to the Nakuru context. However, the list of alternatives used later will be exemplary, neither will it be exhaustive as far as the various possibilities is concerned. Instead, the exercise and calculation must be understood as a guideline to be followed to ensure a realistic result of the cost comparison procedure.

3.2 Investment Costs and Running Costs

It has to be differentiated between investment and reinvestment costs (Capital Expenditures - CAPEX) and running costs (Operational Expenditures - OPEX). While the initial investment costs are rather simple to estimate and to compare, reinvestment costs and running costs can depend on many factors. However, both need to be taken into consideration when calculating and comparing costs.

3.2.1 CAPEX - investments costs

According to Seicht (2001) "investment decisions and financing decisions are the most important decisions to be made in an economic context". Therefore, the analysis of the costs beforehand is of very high importance and should be done with much care. Investment costs occur mostly before starting operations, running costs occur mostly during operations and may be fix or variable.

The LAWA guidelines describe CAPEX as one time expenditures required to start, run or expand the operations. Investment costs usually require an important part of the funding of an endeavour. From an accounting perspective, at the time of acquisition, an investment does not lose its value. Instead, it is simply a change of the form of the value. Over time a certain part of the value is continually written off as the actual value of the investment decreases as the object ages. Those write offs are the true costs of the ownership (Haberstock, 2008). Still, while from a accounting perspective the costs will only appear over time, from a investment point of view this is not the case (Länderarbeitsgemeinschaft Wasser, 2004). The goal of the procedures described in this thesis is to give an estimate of the actual costs that have to be met. "Write offs" in the accounting sense are relevant when it comes to judging the value loss of an investment, however they do not necessarily represent the amount of money needed at a point in time. The yearly costs that will be calculated later over the period of the lifetime of the investments do however include a linear value loss over time as the object reaches the end of life.

3.2.2 OPEX (Operational Expenditures) - running costs

Running costs are recurring expenditures, in regular or irregular intervals, that are required to continue operation. Some OPEX are related to the amount of services delivered. An example would be for instance the materials needed for manufacturing a product: the more products that are produced, the more material costs will occur (Seicht, 2001). Other running costs are rather invariable, such as a yearly fee for having a registered business. Unlike CAPEX, OPEX are recurring in shorter periods of time (Länderarbeitsgemeinschaft Wasser, 2004).

To gain a better overview, accounting and cost calculation manuals suggest various ways of classifying running costs into distinct categories. The LAWA guidelines suggest as a starting point three categories of running costs: personnel costs, material costs and energy costs. In this work, the costs will be separated by production factors (Haberstock, 2008) into the following categories:

- **Material and Energy Costs:** Costs of the materials used during the process. Here it is important to know both the quantity and the price per unit. Those costs would be for example food for the donkey.
- **Labour Costs:** Costs related to the employees. They include the salaries and also other factors such as social security.
- **Taxes, Administrative Fees:** Costs that are to be paid to the the state, municipalities etc. They may be both mandatory or directly related to services used.
- **Service Costs:** Costs for services from other companies or individuals such as repairs or insurances.

3.3 Common Formulas used for the Calculations

3.3.1 The Real Interest Rate

The real interest rate is the actual interest rate while taking into consideration the nominal interest rate and the loss of value due to inflation. If the interest rate was equal to the rate of inflation, then the real interest rate actually would be 0%.

The formula to calculate real interest rate :

real interest rate $= \frac{\text{1 + nominal interest rate in \%}}{\text{1 + inflation rate \%}} - 1$

Example: According to the Central Bank of Kenya, the current inflation rate (June 2011) for the last 12 months is 5.96%, according to the same source the rate for commercial loan is 13.92% (*Central Bank of Kenya*):

$\frac{1 + 0.1392}{1 + 0.0596} - 1 = 0{,}075 = 7.5\%$

Hence, the real interest rate would be 7.5%.

3.3.2 The Compound Factor

Considering price data from the past, the LAWA Guidelines suggest that it is enough to adjust them according to the general variation of prices (“compounding”). However, in cases such as discussed in this paper, due to the difficult comparability and the accessibility of price data, as much fresh data as possible should be acquired. This is especially important, if the period in question is longer than just a few years, as inflation is usually more volatile. For this work, much price information from the year 2010 will be used and therefore compounded to 2011 prices.

The formula to be used for compounding is:

$(1 + \text{inflation rate})^{\text{number of years from base year}} \cdot \text{price of good in the past}$

Example: According to Grambauer (2010), in 2010 a donkey cost 8000 KES (at the time €74.74 at a conversion rate of 108:1). Furthermore the last year the inflation rate was 13,92% (*Central Bank of Kenya*). Hence, the following applies:

$(1 + 0.1392)^1 \cdot 8000$ KES = 9113.6 KES (= €72.33 at an exchange rate of 126:1 as of 2011/06/11 (*Central Bank of Kenya*))

3.3.3 Present Discounted Value

In this paper, when talking about nominal costs, the value considered is always the "present discounted value". The present discounted value allows for a simple overview of an investment's costs over its lifetime. To calculate the current value of an amount spent in the future, the amount has to be discounted with the real interest rate that is expected during the period. Only when the costs of one good develops differently than general inflation, this has to be accounted for differently. It is essential that all future costs are discounted correctly so that the comparison is not distorted (Länderarbeitsgemeinschaft Wasser, 2004). The LAWA guidelines strongly discourage unfunded assumptions when it comes to the future development of interest rates and inflation. Over longer periods of time, the LAWA guidelines expect the real interest rate to be quite stable in Germany and Austria. However, in developing countries this might not be the case.

3.3.4 The Discount Factor

The discount factor is the factor by which a future cash flow must be multiplied in order to obtain the present discounted value. The formula for one time investments in a given numbers of years in the future is:

$\text{Discount Factor} = \frac{1}{(1 + \text{interest rate})^{\text{number of years since base year}}} - 1$

If the real interest rate was 5.96% as calculated earlier and assumed to be stable over a period of 10 years, one donkey with an investment price of 9113.6 KES in the base year would have to be refinanced after 10 years. The following calculation would apply:

$9113.6 \cdot \frac{1}{(1+0.059)^{10}}$ = 5137.2 KES in the base year

It follows that a low real interest rate would favour investment decisions that are capital intensive, while a high interest rate would disfavour such investments in comparison. As said before, due to the volatility of both inflation and nominal interest rates, the prediction over a long amount of time, even in countries with every stable currencies, is highly speculative (Länderarbeitsgemeinschaft Wasser, 2004). Therefore, for the calculations later an assumption of a real interest rate of 5% will be used. The sensitivity analysis however will test the results for real interest rates between 3% and 9%.

3.3.5 Yearly Costs

While the present discounted value is an important indicator, it can be equally interesting and important to calculate the yearly costs of a project. For this the investment costs are multiplied with a factor taking into account the amount of years and the real interest rate. The result is the distribution of discounted yearly costs over the time span. When the running costs are added to this amount, the result are the yearly costs of an investment:

$$\frac{\text{interest rate}\cdot(1+\text{interest rate})^{\text{life span of investment}}}{(1+\text{interest rate})^{\text{life span of investment}}-1}\cdot\text{yearly investment costs}+\text{yearly running costs}$$

Different options to achieve one goal may have different life spans, but in most cases to truly compare the costs, they must compared for the same life span. If the life spans are different, this can be achieved by calculating the costs over the smallest common multiple of the life spans. However, if the time spans of the investments are different but the initial investment takes place at the same time, the real reinvestment costs equal the initial investment costs and the running costs are constant, then according to the LAWA guidelines a comparison of the yearly costs may be sufficient (Länderarbeitsgemeinschaft Wasser, 2004).

3.4 The Service Chain / The Services of MEWAREMA

In the sanitation system considered here, there are five functional groups (Sustainable Sanitation Alliance, 2010) as seen in Figure 7:

- 1 - The user interface: In the case of the system described in this thesis, this is a UDDT.
- 2 - Collection and storage: With UDDTs, this involves a container for the faeces as well as ideally a container for the urine. Pre-treatment occurs during collection and storage. The correct implementation of this step is essential to assure the functioning of the UDDT.

- 3 - Transport: The filled storage containers must be emptied in given intervals and transported to the main treatment site. Reliability of this service is required to keep the UDDTs functioning. This step also requires safety precautions to evade possible dangers for the workers.
- 4 - Treatment: The treatment finalises sanitation and produces fertiliser. In the case of co-composting, this may include also for example organic waste.
- 5 - Reuse: The fertiliser produced from the excreta and possibly the organic waste is reintroduced into the food chain by using it for agricultural production.

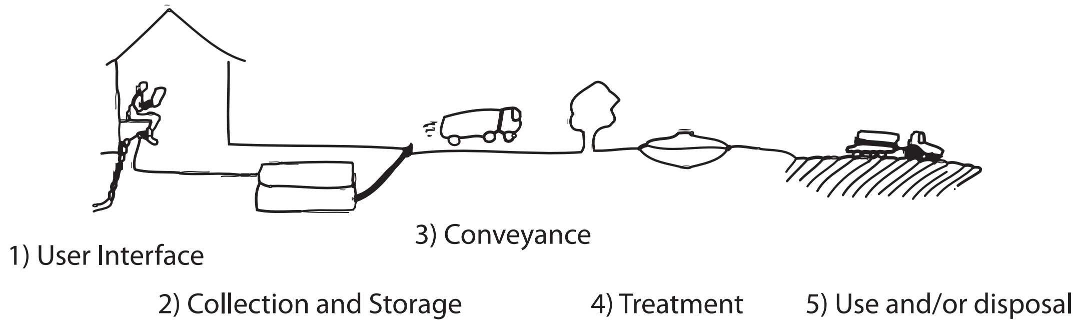

Figure 7: Service Chain for UDDTs used according to ecosan principles (Picture: Jan Wijkmark in Sustainable Sanitation Alliance, 2010)

MEWAREMA in Nakuru is responsible for the steps 3 and 4 (Bräustetter, 2007). It does not offer to build toilets and is not in charge of the pre-treatment. Equally, as MEWAREMA has no own agricultural activities, the fertiliser is sold for reuse to others.

The services delivered by MEWAREMA have to fulfil the following main functions:

- The excreta have to be transported from the customers to the treatment facility. Only if this is assured, the UDDT infrastructure will continue to function. It is also a prerequisite so that the UDDT will not become a dangers to human health or the environment. In addition, organic wastes may be collected.
- Once in the treatment facility, the excreta (already pre-treated in the case of faeces and urine due to the waiting period) and the organic waste are co-composted. This step will render the excreta fully sanitary and convert the organic waste and the excreta into a natural fertiliser rich in nutrients.
- The final product is sold as organic fertiliser to individual or bigger customers.

3.4.1 The Service Chain and the Costs and Variables involved

3.4.2 Collection and Transport

For the collection and transport step, which is what this thesis concentrates on, there is the possibility of using different vehicles with different characteristics and costs. Those characteristics are speed, maximum load, running costs but can also concern the way the excreta is collected. For example there is the possibility of using specialised vehicles with vacuum tanks for the collection of urine.

When planning to start such a business, the first decision that needs to be made concerns the question what kind of services are to be offered and what types of materials will be collected and treated. In addition to the organic wastes, which MEWAREMA is already collecting from the local dump site for composting, MEWAREMA is also supposed to collect both faeces and urine (Grambauer, 2010).

In the context of ROSA and the UDDT infrastructure, the collection of faeces is the most essential service to be rendered. As described, faeces are the biggest hygienic problem. Their removal is a prerequisite for the continuous functioning of the UDDTs. In peri-urban areas, this is the one problem that people are most likely to be willing to pay for a service (ROSA Project, 2010c; Muchiri and Mutua, 2010; ROSA Project, 2010b). Only with collection and transport being done, the rather expensive acquisition of a UDDT will bring the expected benefits and can be justified .

When it comes to collecting urine, the situation is a bit different. It is easier to dispose of urine by various means without the same immediate dangers to health. Therefore, many UDDT owners are not be willing to store the urine and to pay a fee for the service to collect it (ROSA Project, 2010a). When collected, however, due to the high nutrient content of urine, it can either be stored and then used as a fertiliser directly on its own or, in the case of co-composting faeces and organic waste. It can be added to the compost instead of water to keep a moisture at high levels and to enhance the nutrient value (Bräustetter, 2007). As urine output per person is much higher than faecal output, the collection of urine will require more effort and costs per person than the collection of faeces.

Collecting organic waste as a service can be very complementary to collecting faeces and urine, as it can be used for co-composting. Organic wastes are very common, they occur at high volume in in places such as markets or hotels. The collection thereof, due to this centralised nature, can be a cost effective source for co-composting materials for the production of organic fertiliser. While the potential number of clients with UTTDs is restricted, at least in the beginning, collecting organic wastes can open up the services to a wider cliental. Clients such as hotels or markets might be willing to pay for the disposal. While in reality MEWAREMA obtains the organic waste from the dump side (Bräustetter, 2007), for the calculations of this paper it will be considered that it is especially collected as it would be the case in most scenarios.

3.4.3 Treatment

The treatment steps in the examples used here consist of co-composting, but other options are possible such as drying for example. For co-composting, a shed is required to protect the compost from rain and animals. If urine is collected, a tank will be required as well. Co-composting is a composting procedure where organic waste and faeces are composted together, possibly with the addition of urine. Mixing organic wastes and faeces at a certain ratio will improve the composting process and increase amount of the fertiliser output produced. For co-composting of organic waste and faeces, a mixing ratio of 2:1 is suggested (Bräustetter, 2007). In this thesis, for the examples it will be considered that only as much organic waste is collected as is necessary for co-composting at this ratio, even though in reality this can be different of course.

Bräustetter (2007) describes the treatment processes used by MEWAREMA in Nakuru :

- Banana fibres are placed at the bottom as a cover
- The water-content is maintained by 40% by continuous supply of water
- For 2 to 3 days, temperatures between 50°C and 70°C
- To sustain the process, waste is turned every 3 to 4 days depending on moisture content and rate of decomposition
- After 21 days compost is ready and sieved
- According to estimates, up to 2 tons of material can be treated in Nakuru at a time

In this thesis, the treatment of excess urine that is not used for co-composting is not considered. It is however in reality of course important that the urine is also disposed of in a safe manner and not only collected and released into the environment.

3.4.4 Re-use of the compost

The product, namely the compost, is of important value for the organisation or company that is delivering the collection and treatment services. This value may be the income generated by selling this organic fertiliser to customers. In Nakuru for example, it was planned that the compost produced by MEWAREMA would be mainly sold directly to

NAWACOM, a company that produces fertiliser at a larger scale. However, a small part of the production is given to customers as a marketing incentive MEWAREMA (Grambauer, 2010). Other companies might want then again want to sell their compost directly. Possibilities would include marketing the compost to smaller customers such as farmers or to find instead one big end user that would purchase large quantities of compost. For example, it could be thought of a scenario where transport costs not only occur when collecting the excreta and the organic waste but also, when delivering the product to the customer. Depending on the distances and amounts of compost to be transported, this factor might also influence the choice of the vehicles used for transport.

3.4.5 Capex Cost Factors

General Investments A certain amount of office infrastructure is required to run a business. Activities required may for example be book keeping or being in contact with clients. The exact requirements will depend on the kind and the size of the business. A CBO whose primary concern is to maintain a restricted amount of the toilets functioning and to use the fertiliser output for its own use might not require much of this. A company aspiring to serve a big number of clients on the other hand would require a more representative setting, suitable also for example for meeting business partners. In a context such as MEWAREMA, most of this already exists and thus will not have to be bought to establish the services for the UDDT infrastructure. It is therefore not considered further in this thesis for the calculations.

The Collection and Transport The collection and Transport step requires investments in a vehicle and possibly a cart for transportation.

Treatment CAPEX for treatment include a drying shed for the co-composting, a urine tank, tools and possibly some construction to temporary store the compost. Normally there would also be factors such as the land required for composting, however as MEWAREMA already had the land this will not be considered in the calculations.

3.4.6 Opex Cost Factors

Personnel Costs By far the biggest part of the personnel requirements will depend on the amount of service that is actually delivered, but a certain minimal requirement of personnel independently of that will be required as well. Those minimal requirements are certainly a supervisor to oversee operations. Possibly there could of course also be a secretary if the business is sufficiently big. The actual work load of the supervisor will largely depend on the size and the structure of the business. In the case of MEWAREMA, as delivering collection and treatment services for UDDTs are only an extension of the initial business model, the actual surplus of work and thus costs for the supervisor were estimated to be quite low at 2,734 KES per year (Grambauer, 2010) in this particular case.

Most of the personnel costs will be due to the workers doing the manual work of collecting and transporting the waste on the one hand and co-composting the waste on the treatment site on other hand. Estimating the amount of work required is not always a simple task. The workers of MEWAREMA for example are paid on a per diem basis. However, due to the nature of the tasks, it is not possible to simply add up the time of actual work required for the tasks to come up with the number of days required (Grambauer, 2010). For instance, the composting process requires a turning of the piles every 3 to 4 days. Thus, independently of the amount of compost being treated, every three to four days two workers need to be present and be paid for one day of work each. While those costs may scale well once a certain threshold of activity is reached, in the beginning those costs are rather invariable. Grambauer (2010) has estimated that the labour expenses for co-composting at MEWAREMA in the first 5 years would be rather stable at 192 working days (=8 days a month for two workers) per year, despite the fact that overall throughput was expected to somewhat increase. In this thesis, labour costs for co-composting in the case of MEWAREMA, at least for the foreseeable future, will therefore be regarded as de-facto fix costs and variations will not be considered in the calculations.

The problem is similar for calculating the amount of work required for the collection and transport of the materials. While the workers are paid per diem, depending on the amount of clients there might be considerable losses due to the fact that it is not always possible to wait until enough excreta can be collected to justify a trip. When estimating the labour costs, such factors that are difficult to quantify must still be taken into consideration.

Depending on the context, the wages of the employees are also subject to taxes, social security or other factors such as insurances. Those costs fall into the “personnel costs” category. It is the same with training measures. As the workers are dealing with a specialised technology and potentially dangerous substances, it will be essential to train the workers before they can safely deliver the services. Equally as important training will be needed on co-composting to produce high quality fertiliser. Each new worker will have to undergo such a training and thus produce costs before (s)he will be fully functional.

Unless (s)he is fulfilling one of the above mentioned functions, it is important to note that the personnel costs above do not include a salary for the owner of the service (if applicable). Therefore, if for example the business owner expects to receive a certain revenue, but is not doing any work per se as and therefore is not on the payroll, then such an account needs to be taken care of separately. Inversely, it is a common mistake for a business owner that is participating in the work to underestimate the salary required for himself or herself. The salary therefore should always be set realistically to meet the demands, even though this might have negative effects on the total costs. Anything else will produce an unrealistic result (Haberstock, 2008).

Material and energy costs If donkeys are used, then water and food would be needed to feed the donkeys. If the treatment choice is co-composting, then in most cases some water will be necessary for this process. However, depending on the amount of urine collected, less water would be required (Bräustetter, 2007). Furthermore as hygiene is essential when dealing with excreta, water will be required for cleaning measures for the workers as well as for cleaning of the vehicles and tools used. Water costs depend strongly on the local context. In an area where water is abundant the water costs might not be important, especially since for composting there is no need for drinking water quality. In an arid context, those costs might be a more important factor. For cleaning activities there are also other expenditures such as soap.

When it comes to energy, the requirements depend a lot on the size of the company and the way it is delivering the services. Taking MEWAREMA as an example, electricity for instance is needed neither for transport nor for treatment. It is however a factor for administrative tasks, for example if computers are used for book keeping and other administrative purposes. Unfortunately for MEWAREMA there is no data available. Depending on the vehicle used, gasoline is a cost factor. As gasoline prices are generally volatile and expected to rise, for this factor it might be particularly interesting to do a sensitivity analysis.

If the organisation has an office, some costs would be designated to supplies such as paper or possibly toner for the printer. For MEWAREMA, there is no data available.

Service costs Service costs are for example the costs for the maintenance of the motorised vehicles if this is done by an external service. The analysis of composition of the compost produced also is a task that can only be done by external services, such as for example a university laboratory. Also telephone costs or travel costs fall into this category. Insurances or the costs of a loan are service costs as well. In this work, only service costs for maintenance of vehicles and other investments will be considered, as reliable information on other costs are unavailable.

Public Costs and Fees Public Costs and Fees are costs that need to be paid to the town, the municipality or similar in order to be able to run the business. Such costs may be a fee for an entry into the register of companies or again the permission to offer waste collection services in a given area. Taxes on revenue are not considered by the cost calculation. However, when making a business plan, unlike in the cost calculation as applied here, then taxes on income of course need to be considered. Once again unfortunately information is lacking, which is why public costs and fees are not considered for the calculations, even though ideally it should be.

4 Results

4.1 Applying the cost calculation procedure to the Nakuru Scenario

In this part of the thesis, the cost calculation guidelines will be applied to the Nakuru scenario. It will be used to assist in making a choice on the transportation solution for the collecting and transport step of the service chain. Different transport solutions that could be used for an organisation like MEWARENA will be compared. As the transport part of the service chain offers quite a variety of possibilities, performing such a calculation here seems particularly adequate. To do so, the steps suggested by the LAWA guidelines as indicated in Figure 6 on page 19 will be followed.

Unfortunately, there is not sufficient data available to apply a similar approach to the other steps of the service chain. Instead, before looking at the options for transport, an attempt will be made to calculate the non transport related costs that would be faced by MEWAREMA over a period of 10 years. This calculation will be based on available data and assumptions.

4.1.1 General Costs and Costs of treatment

General Costs and Costs of Treatment, Identification of the costs: Due to a lack of data, it is not possible to scale the costs over varying amounts of compost produced. Instead, the costs will be calculated for what is assumed to be the production by MEWAREMA within the first five years years of offering the service (Grambauer, 2010). The available and assumed data is summarised and categorised in Table 3.

Overview of non-transport related costs	
CAPEX:	
Cost Factor:	**Costs**
Tools:	10,000 KES (own assumption)
Urine Tank:	68,352 KES (Grambauer, 2010)
Initial Drying Shed:	7,291 KES (Grambauer, 2010)
Reinvestment Drying Shed after 5 years (discounted):	5,713 KES
Total CAPEX:	91,356 KES
OPEX:	
Cost Factor:	**Costs**
Personnel:	
Labour:	65,618 KES (Grambauer, 2010)
Supervisor:	2,734 KES (Grambauer, 2010)
Material and Energy:	
Office Supplies:	5,000 KES (own assumption)
Services:	
Yearly Maintenance Tank:	6,825 KES (= 10 % of CAPEX) (Grambauer, 2010)
Yearly Maintenance Shed:	365 KES (= 5 % of CAPEX) (Grambauer, 2010)
Public Costs:	
Unknown	-
Total OPEX:	80,542 KES

Table 3: Treatment: General overview of costs fix costs and treatment costs over a period of 10 years

Based on this, Table 4 shows of the total net costs and the yearly costs over a lifetime of 10 years and a real interest rate of 5% for an annual compost production of up to 18,270 kg (amount expected in year 5 years of operation of MEWAREMA by Grambauer (2010)).

Even though it is not possible to scale those figures, they will be the object of a sensitivity analysis to see what effects fluctuations of labour costs and real interest rates have on the price per kg of compost (assuming a production of 14,070 kg per year). The results can be seen in Figure 8.

Net Present Costs over 10 years at real interest rate of 5 %	
Factor	**Costs**
Total CAPEX:	91,356 KES
OPEX for lifetime of 10 years, discounted:	621,999 KES
Total net present costs:	713,355 KES
Converted to yearly costs at real interest rate of 5 % over 10 years	
CAPEX converted into yearly costs:	11,831 KES
Total OPEX per year:	80,542 KES
Total costs per year:	92,373 KES

Table 4: Treatment: Comparison of net present costs and yearly costs over a period of 10 years at a real interest rate of 5%

As shown in Figure 8, due to the labour intensity of the work as described earlier, changes in labour costs have a strong and direct impact on the costs of compost. At the same time, the effects of changes in real interest rates is very small and a change of real interest rate from 3% to 9% results in an increase of costs per kg of less than 0.5 KES. Of course, in a scenario where factors such as perhaps an office or land and would need to be purchased and thus increase the CAPEX, the impact of the real interest rate would be somewhat bigger.

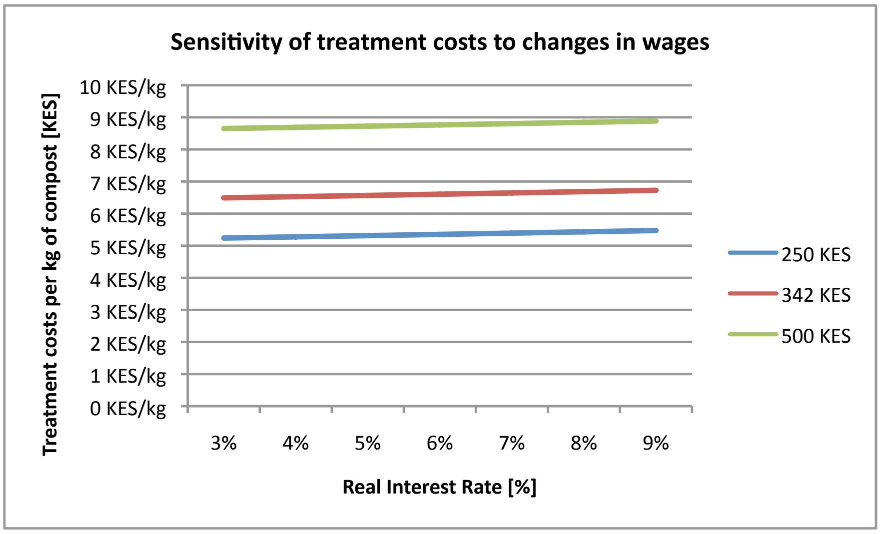

Figure 8: Treatment: Sensitivity Analysis for expected non-transport related costs with labour prices ranging between 250 KES and 500 KES per day per worker at real interest rates between 3 % and 9%

4.2 Stage I of the Cost Comparison Calculation

Stage I of the cost comparison procedure will be the same for all three scenarios considered.

Step 1: Analysis of the problem and definition of the goal. The problem is that faeces and urine need to be collected from the UDDTs. In addition, organic waste needs to be collected from bigger, more institutional customers such as markets or hotels. The goal is to deliver those materials to the treatment site at comparably low costs. Cost effectiveness is essential, because both the income from the collection process and the income from selling the final product (compost) later must be sufficient to meet the costs.

Step 2: Finding and description of the options. There are various means of transport available. Considered are a donkey cart, a motorised tricycle and a small pickup truck. Already at this point, there must be an evaluation of the suitability of the vehicle for the terrain. For this example, it is assumed that all three vehicles are equally apt in the given scenario. However, in reality a review of the state of the roads and their compatibility with the transport options will be required. This is especially true if the roads are not paved as heavy rains may have a severe impact on their quality and hence on the aptitude of certain transport options.

The choice of options proposed and their attributes are to a certain point arbitrary, as objects such as a tricycle or even a donkey cart are not standardised. They exist in various sizes with different ages, investment costs and other varying parameters. Therefore, to obtain a plausible result for a particular case, the calculations and comparisons made here must *always* be recalculated using the specific information of the objects to be compared. While the tendencies of the results obtained in the examples might have general value, they are nothing more than that.

The basic assumptions for the vehicles are summarised in Figure 5.

- **Donkey with cart:** Using donkeys to pull a cart is one of the least expensive options for transportation considered and one widely used for transportation and agriculture in developing countries in general. Donkeys are very resistant to all sorts of external pressures such as heat, drought or diseases (Hagmann and Prasad, 1995), making them ideal animals for such purposes. However, while investment costs of animals such as donkeys are relatively low, the costs and efforts that come with ownership of a donkey are only to a point depending on the actual work delivered. Instead, there are many fix costs of ownership such as food or housing (Jones, 2000). In the case of MEWAREMA, special costs for housing and such do not seem to apply (Grambauer, 2010) and are not considered for the calculations. However, depending on the context, such factors would need to be considered.

  For the scenarios, a cart suitable for transporting up to 300 kg of material pulled by two donkeys requiring two workers for safe and sound handling as it is intended to be used by MEWAREMA (Grambauer, 2010) will be considered as an option. However, other variations are of course possible.

- **Tricycle:** Tricycles are small motorised vehicles that can be used for transport and that are popular for small businesses in developing countries. While their small size is restrictive in terms of loading capacity, they can access narrow roads and other areas that cannot easily be accessed by larger vehicles (Shibae, 2009; Slob, 2005). Due to their relatively high speed (Stieber, 1999), the labour costs are lower as less time is needed for transport. Also, the lighter construction and smaller load reduces fuel consumption. Investment costs are small as well in comparison to many other motorised options, which also signifies lower maintenance costs for the vehicle during operation.

  For the scenarios, a tricycle able to transport up to 300 kg at a time will be considered, operated by two workers at a time.

- **A pickup truck:** A small pickup truck is a rather expensive investment compared to the other two options. However, it is both fast and has a big capacity. Other costs of ownership include maintenance, insurance and administrative fees, which are also higher, even though no data is available on insurance and administrative fees. The benefits of the truck would be its capacity to serve a big number of customers, also over longer distances and thus requiring relatively little labour. Its strength is the transport of big loads over long distances at high speeds (Stieber, 1999). The disadvantage, even though not considered in this work, is its size, which may render it inapt to access certain areas.

  For the scenarios, a truck able to transport up to 1,200 kg and operated by two workers will be considered.

Overview options for transport			
Option:	**Donkey Cart**	**Tricycle**	**Small Truck**
Vehicle:	18,228 KES (Grambauer, 2010)	100,000 KES	450,000 KES
Cart:	39,872 KES (Grambauer, 2010)	-	-
Yearly Maintenance Vehicle:	-	15,000 KES (= 15% of CAPEX)	67,500 KES (= 15% of CAPEX)
Yearly Maintenance Cart:	2,791 KES (= 7% of CAPEX) (Grambauer, 2010)	-	-
Lifetime:	10 years	10 years	10 years
Average Speed:	3 km/h	20 km/h	20 km/h
Capacity:	300 kg (Grambauer, 2010)	300 kg	1200 kg
Gasoline consumption per km:	-	4 litres	12 litres
Number of workers required:	2 (Grambauer, 2010)	2	2

Table 5: General overview of different transporting options considered. Values assumed if not indicated differently.

Step 3: Check Applicability of Cost Comparison Procedure: The selection of vehicles has already tested for their suitability for the terrain. Other factors do not apply here. Therefore, the main argument for deciding on one or the other option are the costs, thus the CAPEX and OPEX involved. This step concludes that the cost comparison calculation is an applicable method to use, therefore it can be proceeded to Stage II. If for example the vehicles had not already been evaluated for suitability for the terrain at this point, then in the end a cost calculation procedure might come up with the seemingly most cost effective but not necessarily with an adequate solution. At this point of the procedure, it is essential to review if the cost calculation procedure can give a plausible answer given the choice of options.

4.3 Stage II of the Cost Comparison Calculation

In the following section, three different scenarios will be calculated to show the effects that different variables can have on the transport costs. As before, the steps suggested by the LAWA guidelines will be followed.

4.3.1 Scenario 1: Nakuru - data comparable to current situation

Scenario 1 tries to assume a context corresponding to the the actual Nakuru context. An overview the data and assumptions used for the calculations can be found in Table 6.

Context for Scenario 1	
Variable:	**Value:**
Personnel costs per worker per diem (8h):	342 KES (Grambauer, 2010)
Gasoline costs per litre:	115 KES (Bloomberg, 2011)
Average distance to customer from treatment area:	1 km
Distance between two customers on a trip:	0.2 km
Time required per customer:	10 minutes
Time required for unloading and various tasks per trip:	70 minutes
Average % load per vehicle per trip:	80% full
Minimum faeces transported per year:	6,700 kg (Grambauer, 2010)
Minimum urine transported per year:	12,970 litres
Size of container:	50 kg / 50 l
Average distance to customer organic waste:	2 km
Amount of organic waste per year:	13,400 kg
Amount of compost producer per year:	14,070 kg (Grambauer, 2010)

Table 6: The variables describing Scenario 1. Values assumed if not indicated differently.

Scenario 1, Stage II: Actual cost comparison calculation

Step 4: Identification of the costs: The investment costs, the running costs as well as the lifetimes of the different vehicle options differ significantly. It is the same for the potential of transporting excreta and organic waste, expressed by capacity and speed of the vehicle. The choice of the vehicle depends thus on factors such as the available funding and the requirements in terms of capacity and prospects of future growth. The costs of the options in scenario 1 are indicated in Table 7.

Calculation of the running costs The total excreta to be collected and transported from the UDDTs is 6,700 + 12,970 = 19,670 kg.

As described, it is considered that a trip will be made if the vehicle can be filled by 80%. In the case of a 300 kg donkey cart, this gives a load of 240 kg per trip or 82 trips per year. If 240 kg are transported each time, this equals ca 4.8 clients served per trip. It is furthermore considered that the average distance to a client is 1 km and the average distance between 2 clients on a trip is 0.2 km. The total distance for a trip would be $2 \cdot 1$ km +(5 - 1) $\cdot$ 0.2 km = 2.8 km. This is of course somewhat theoretical, however on average this should give a workable result.

As the donkey cart moves with 3km/h, the time needed for this distance is
$\frac{60}{3\,\text{km/h}} \cdot$ 2.8 km = 56 minutes.

At each client 10 minutes of time is spent, thus 4.8 $\cdot$ 10 = 48 minutes. Furthermore for each trip 120 minutes are taken into consideration for tasks like emptying the cart and other things. The total amount of time spent is thus 56 + 48 + 120 = 224 minutes or 3:44 hours. The wage for a worker per day is 341.76 KES or 42.72 KES per hour or 0.712 KES per minute. At 82 trips per year à 224 minutes for 2 workers, this means 82 $\cdot$ 224 $\cdot$ 2 = 36,736 minutes or 26,156 KES in salary for the workers per year for transport. It is of course not realistic to calculate the wages in the given context on a per minute basis, but on average this should equal out.

The need for gasoline for a vehicle has to be calculated to derive the amount spent on fuel. Taking the tricycle, just as for the donkey cart one trip à 80% for a 300 kg tricycle has the distance of 2.8 km: 2.8 $\cdot$ 0.04 = 0.112 l per trip. At 82 trips a year this means 9.2 litres at a price of 115 KES per litre (Bloomberg, 2011): 9.2 $\cdot$ 115 = 1,058 KES for gasoline a year. The total costs per trip are labour plus fuel.

Furthermore, the mixing ratio for co-composting between organic waste and faeces is 2:1. If 6,700 kg of faeces are co-composted, 13,400 kg of organic waste need to be collected. While this is not the case for MEWAREMA in reality, organic wastes in the scenarios will be collected at central places such as markets. For this work, an average distance to the markets of 2 km is assumed, thus one trip will be 4 km. The average load will also be 80% of the maximum capacity. In the case of the donkey cart this means 240 kg equalling 56 trips per year. At a speed of 3km/h the travelling time would be 80 minutes plus 120 minutes for activities such as loading and unloading, giving 200 minutes per trip. Over the year this means 200 $\cdot$ 56 $\cdot$ 2 = 22,400 minutes or 15,948 KES. For a motorised vehicle, the fuel consumption would have to be calculated as well.

The total labour costs for transporting faeces, urine and organic waste for a donkey cart as defined in this Scenario would be be 42,104 KES per year. In the calculations further, the same methods of calculation will be used, however only the results will be shown.

Table 7 indicates the costs for Scenario 1.

Costs of transport options			
Option:	**Donkey Cart**	**Tricycle**	**Small Truck**
CAPEX:			
Vehicle:	18,228 KES	100,000 KES	450,000 KES
Cart:	39,872 KES	-	-
Total CAPEX:	58,100 KES	100,000 KES	450,000 KES
OPEX:			
Personnel:	45,137 KES	31,050 KES	12,213 KES
Material and Energy:			
Gasoline:	-	2,067 KES	2,363 KES
Water/Food per year:	242 KES	-	-
Services:			
Yearly Maintenance Vehicle:	-	15,000 KES (= 15% of CAPEX)	67,500 KES (= 15% of CAPEX)
Yearly Maintenance Cart:	2,791 KES (= 7% of CAPEX)	-	-
Public:	-	3000 KES	9000 KES
Total OPEX:	44,960 KES	48,117 KES	91,077 KES

Table 7: Scenario 1: General overview of costs and consumption of the different transport options considered.

Step 5: Methods of Mathematical Finance for Comparison between Present Value Costs and Yearly Costs: With the methods described earlier, Table 8 indicates both as net present costs and at yearly costs. The net present costs allow for a simple estimation of the total costs of the three options over their lifetime. The yearly costs indicate the CAPEX and OPEX each year over the lifetime of the investment.

Net present costs and yearly costs			
Net Present Costs over 10 years at real interest rate of 5 %			
	Donkey Cart	Tricycle	Pickup Truck
Total CAPEX:	58,100 KES	100,000 KES	450,000 KES
OPEX for 10 years, discounted:	347,779 KES	371,631 KES	703,433 KES
Total net present costs:	405,879 KES	471,631 KES	1,153,433 KES
Converted into yearly costs at real interest rate of 5 % over 10 years			
CAPEX as yearly costs:	7,522 KES	12,947 KES	58,264 KES
Total OPEX per year:	44,960 KES	48,117 KES	91,077 KES
Total costs per year:	52,482 KES	61,064 KES	149,341 KES

Table 8: Scenario1: Net present costs and yearly costs over 10 years.

Step 6: Comparison between present value costs and yearly costs: In this scenario, from the results of the calculations it seems clear that the donkey cart is the cheapest. This is true despite its high labour costs. The motorised vehicles, in this scenario, are relatively cheap when it comes to the costs directly related to the services delivered. However, fix running costs for maintenance are high.

Step 7: Sensitivity Analysis: The results from the previous step will now be tested against fluctuations of three variables: real interest rate, price of gasoline and price of labour.

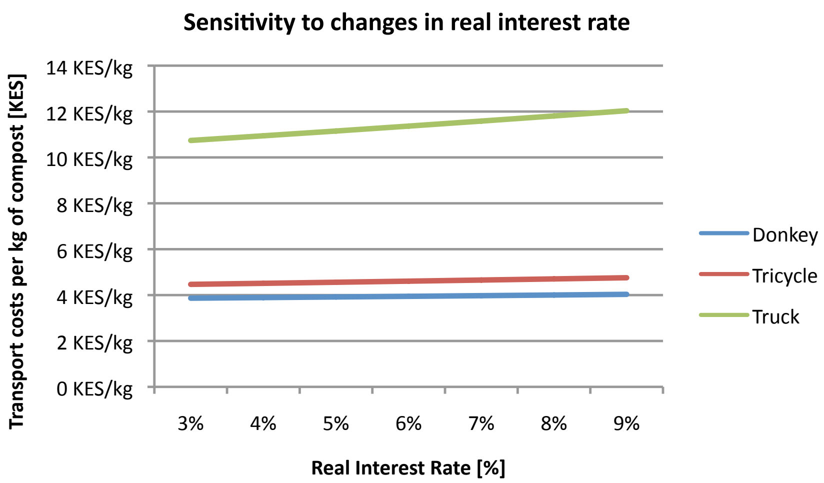

Figure 9: Scenario 1: Sensitivity analysis for real interest rates between 3% and 9% (standard: 5%)

To what extent would the transporting costs per kilogram of compost produced be affected by changes in the real interest rate? The results of the sensitivity analysis are represented in Figure 9. As can be seen, the change in real interest rate does not have a big impact on overall costs for the options that require little CAPEX, namely the donkey cart and the tricycle. In both cases, a change of 6% has hardly any impact. In the case of the pickup truck, which is capital intensive, the impact on the price of the compost is non negligible given that the compost of MEWAREMA is sold at ca 5 KES per kg (Grambauer, 2010). In this scenario the truck is much too expensive in all constellations. There does not seem to be any indicator that a change of interest rate would have an impact on the final choice in this scenario.

What is the impact per kg of compost produced in case of fluctuations of the price of gasoline? Figure 10 shows the development of the prices of the three different options. As the donkey cart does not require gasoline, the price per kg is not affected at all. As for the others, there is a certain impact, but due to the overall short distances of this scenario it is negligible.

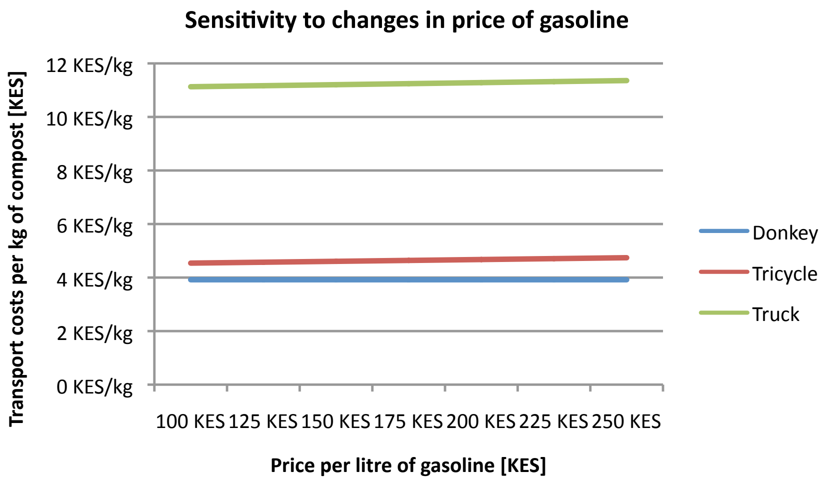

Figure 10: Scenario 1: Sensitivity Analysis for the price of gasoline between 100 KES and 250 KES per litre (standard: 115 KES)

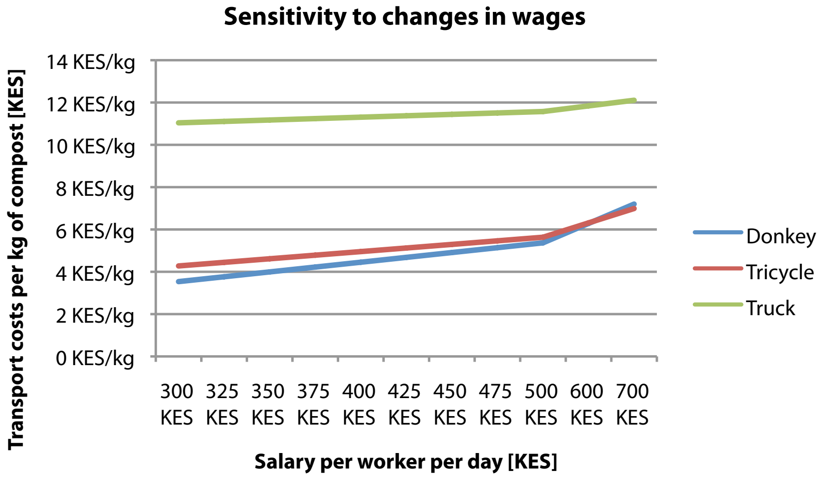

Figure 11: Scenario 1: Sensitivity analysis for per diem wages between 300 KES and 700 KES (standard: 342 KES)

As seen earlier, labour costs are a big portion of the OPEX and there seems to be a general negative correlation between the investment costs and the personnel costs for transport in the three options considered. Figure 11 shows the development of the prices of the three different options. Wages between 300 KES and 700 KES per day are considered. Unlike the impacts of changes in real interest rates or gas prices, this sensitivity analysis shows that the change of salary can have an impact on the overall result of the evaluation. In this case, the critical value where the tricycle becomes cheaper than the donkey cart is a per diem salary of 610 KES per worker. While this would mean nearly doubling the salary and thus might not be likely to happen, it shows that the labour costs have an important impact on the final result.

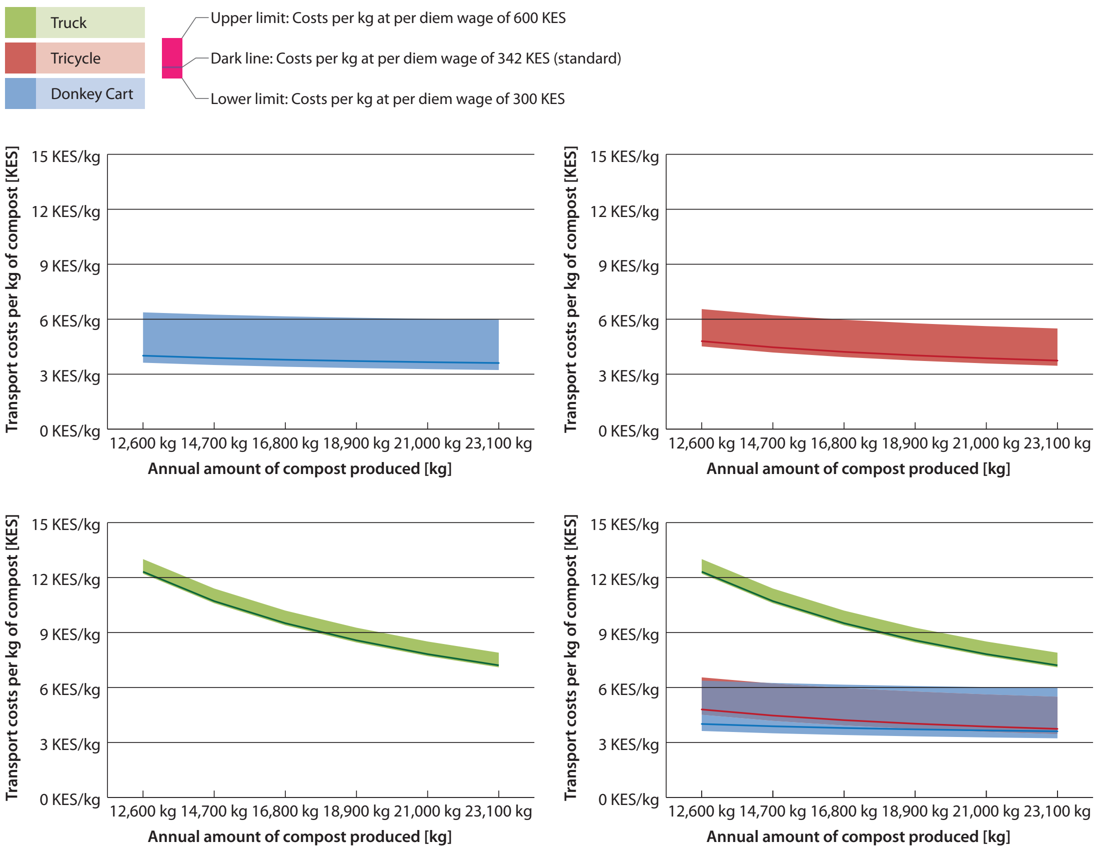

Figure 12: Scenario 1: Sensitivity Analysis for costs per kg of compost produced for per diem wages between 300 KES and 600 KES at an annual compost production between 12,600 kg and 23,100 kg

The above prices are calculated under consideration of the current scenario, in which ca 13,400 kg of compost are produced per year. Labour seems to be the most important factor that could change the results of the cost calculation comparison. Figure 12 shows how the transport costs per kg of compost produced would develop in the standard scenario with labour costs of 342 KES per day if production was increased. In addition, Figure 12 represents a sensitivity analysis taking into consideration salaries between 300 KES and 600 KES per day. While between an annual compost production of 6,000 kg and 11,000 kg per year at low salary levels and even at the current salary the donkey cart stays the most cost effective, at higher labour prices the tricycle becomes more and more competitive. The wideness of the lines indicate the sensitivity of the vehicle to changes in salary costs.

Step 8: Summary and Conclusion of the cost comparison calculation for scenario 1: In Scenario 1, also considering the sensitivity analysis, the donkey cart seems to be the most cost effective option to render the services. While the results of the sensibility analysis have shown that salary costs play an important role and may have an impact on the results, only doubling the salary would change the results of the calculation and the cost comparison procedure.

4.3.2 Scenario 2: Longer distances to customers

Scenario 2 is the same as Scenario 1, except that the distances to the customers are longer. Instead of an average distance of 1 km to the UDDT customers, an average distance of 0.2 km between the UDDT customers and an average distance of 2 km to the markets for collecting organic waste, the average distance to the customers is now 4 km and the average distance between UDDT customers is 0.4 km. The average distance to the markets is also 4 km. A summary of the assumed variables describing the context can be found in Table 9

Context for Scenario 2	
Variable:	**Value:**
Personnel costs per worker per diem (8h):	342 KES
Gasoline costs per litre:	115 KES
Average distance to customer from treatment area:	4 km
Distance between two customers on a trip:	0.4 km
Time required per customer:	10 minutes
Time required for unloading and various tasks per trip:	70 minutes
Average % load per vehicle per trip:	80% full
Minimum faeces transported per year:	6,700 kg
Minimum urine transported per year:	12,970 litres
Size of container:	50 kg / 50 l
Average distance to customer organic waste:	4 km
Amount of organic waste per year:	13,400 kg
Amount of compost producer per year:	14,070 kg

Table 9: The variables describing Scenario 2. Values assumed.

Scenario 2, Stage II: Actual cost comparison calculation

Step 4: Identification of the costs: This section is the same as in Scenario 1 shown in Table 5 on page 35 and thus will not be repeated here.

Step 5: Methods of mathematical finance for comparison between present value costs and yearly costs: Table 10 and Table 11 show an overview over the costs assuming a compost production of 14,070 kg per year, a real interest rate of 5 %, a lifetime of 10 years, a gasoline price of 115 KES per litre and a per diem salary of 342 KES. As the CAPEX are the same as before, they are not repeated in Table 10.

Costs of transport options			
Option:	**Donkey Cart**	**Tricycle**	**Small Truck**
OPEX:			
Personnel:	64,054 KES	34,369 KES	13,295 KES
Material and Energy:			
Gasoline:	-	5,641 KES	5,858 KES
Water/Food per year:	242 KES	-	-
Services:			
Yearly Maintenance Vehicle:	-	15,000 KES (= 15% of CAPEX)	67,500 KES (= 15% of CAPEX)
Yearly Maintenance Cart:	2,791 KES (= 7% of CAPEX)	-	-
Public:	-	3000 KES	9000 KES
Total OPEX:	67,087 KES	55,010 KES	95,653 KES

Table 10: Scenario 2: General overview of costs or consumption of the different transport options considered.

Step 6: Comparison between present value costs and yearly costs: In this scenario, the tricycle seems to be cheaper than the donkey. It is the higher labour costs due to the longer distances to travel that weigh heavier than the higher investment costs and maintenance costs of the tricycle. The pickup truck is still the most expensive option.

Net present costs and yearly costs			
Net Present Costs over 10 years at real interest rate of 5 %			
	Donkey Cart	Tricycle	Pickup Truck
Total CAPEX:	58,100 KES	100,000 KES	450,000 KES
OPEX for 10 years, discounted:	518,025 KES	524,773 KES	738,609 KES
Total net present costs:	576,124 KES	524,773 KES	1,188,609 KES
Converted into yearly costs at real interest rate of 5 % over 10 years			
CAPEX as yearly costs:	7,522 KES	12,947 KES	58,264 KES
Total OPEX per year:	67,087 KES	55,010 KES	95,653 KES
Total costs per year:	74,609 KES	67,957 KES	153,917 KES

Table 11: Scenario 2: Comparison of net present costs and yearly costs over 10 years.

Step 7: Sensitivity Analysis: The results from the previous step will now again be tested against fluctuations of three variables: real interest rate, price of gasoline and price of labour.

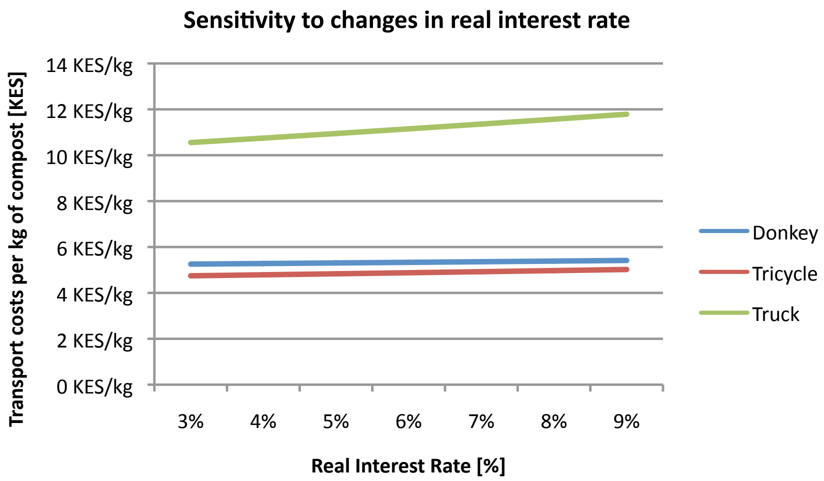

Figure 13: Scenario 2: Sensitivity Analysis for real interest rates between 3 % and 9 %

How sensitive are transporting costs to changes in real interest rate? The results are represented in Figure 13. As can be seen, the change in real interest rate does not have a big impact on overall costs for the options that require little CAPEX. The results are thus the same as in the previous scenario in the sense that this factor does not seem to have a relevant impact. A critical value where the tricycle would become more expensive than the donkey cart is not within reasonable limits.

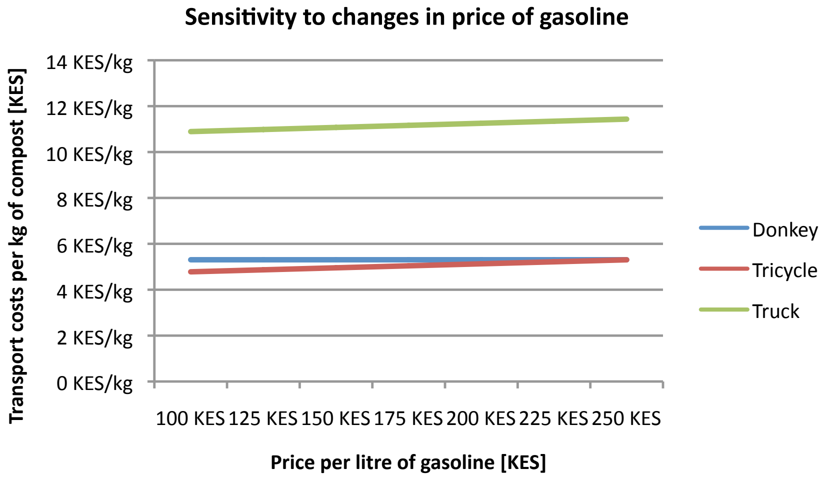

Figure 14: Sensitivity Analysis for the price of gas between 100 KES and 250 KES per litre (current: 115 KES)

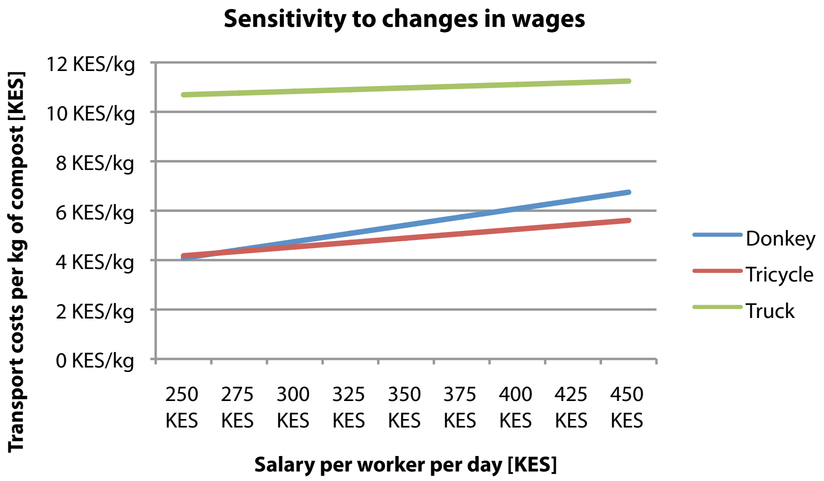

Figure 15: Scenario 2: Sensitivity Analysis for per diem wages between 250 KES and 450 KES (current: 342 KES)

Figure 14 shows impact of fluctuations of the price of gasoline. Unlike in Scenario 1, the tricycle here starts off being the cheapest option. However, the price of gasoline can have an impact on the overall result. All other variables being the same, a critical value for the gasoline price would be reached at about 250 KES, thus somewhat more of a doubling of today's prices. At this point, the higher gasoline prices and the higher gasoline consumption of the scenario outweigh the labour costs of the donkey cart.

As for the sensitivity of labour costs, Figure 15 shows the development of the prices of the three different options considering wages between 250 KES and 450 KES per day. As seen before, at the current labour costs of 342 KES per day, the tricycle is the cheapest option. With increasing labour costs, the difference between tricycle and donkey cart is only accelerated. A critical point where the donkey would be cheaper would be at labour costs of ca 260 KES per day. This is however only of theoretical value, as decreasing labour costs are not likely, especially given their already low level.

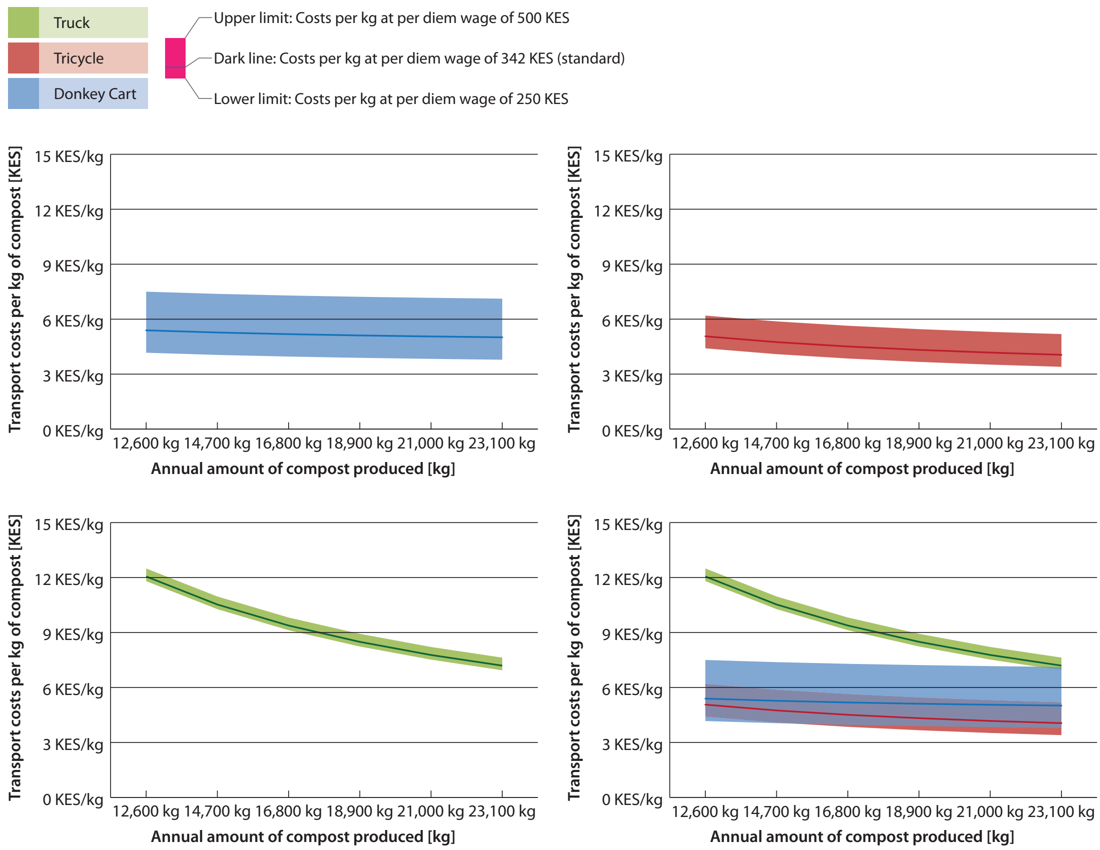

Figure 16: Scenario 2: Sensitivity analysis for costs per kg of compost produced for per diem wages between 250 KES and 500 KES at an annual compost production between 12,600 kg and 23,100 kg

In Scenario 2, unlike in Scenario 1, the development of the sensitivity analysis is tested against both gasoline costs and labour costs for an amount of compost produced between and 12,600 kg of 23,100 kg per year. Figure 16 shows how the costs per kg would develop in Scenario 2 with labour costs between 250 KES and 500 KES per diem (standard: 342 KES).

As it was seen before, only at very low labour costs the donkey is the most cost effective solution. With an increasing amount of matter collected and transported, this trend is further accelerated. Also, as the amount increases, the pickup truck becomes more cost effective. From the graph it can be estimated that at growing throughput, the truck would eventually become cheaper than the other options.

Gasoline prices on the other hand do not seem to have an impact in the actual results. While Figure 17 shows that only at very high gasoline prices and a low amount of compost produced, the donkey would be somewhat more cost effective that the tricycle.

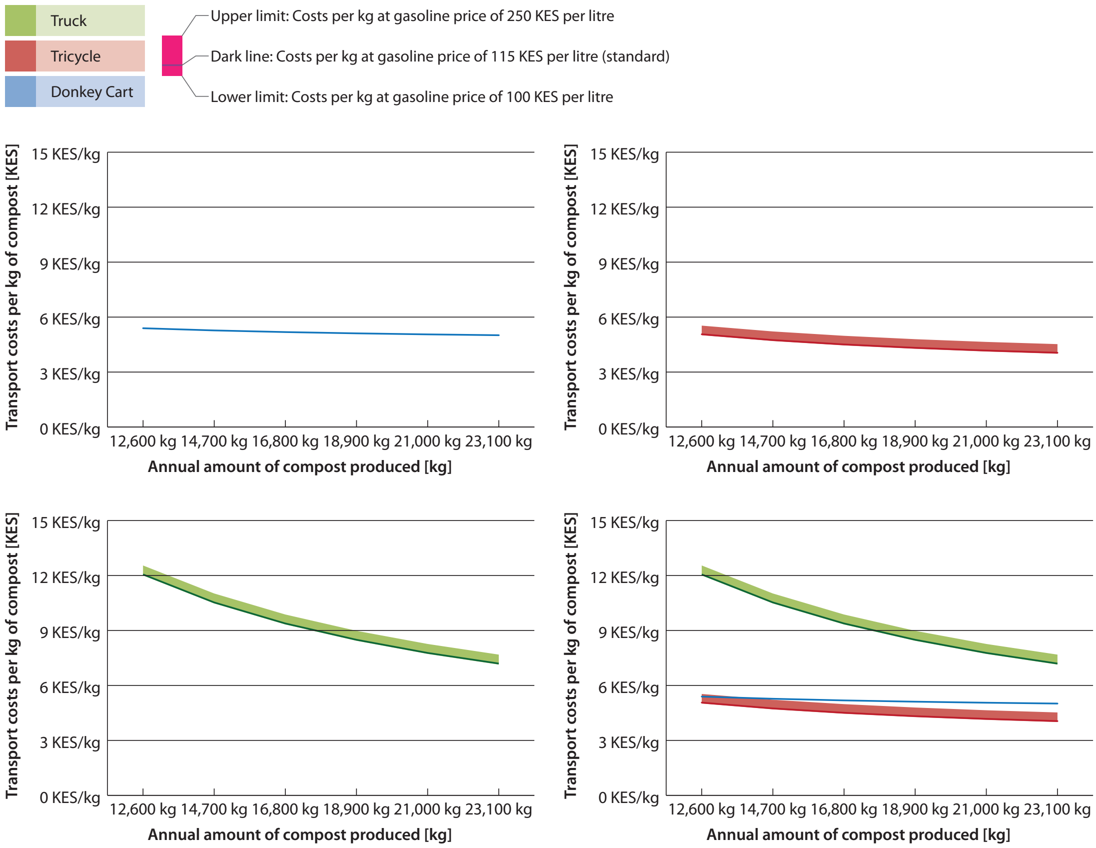

Figure 17: Scenario 2: Sensitivity analysis for costs per kg of compost produced for gasoline prices between 100 KES and 250 KES per litre at an annual compost production between 12,600 kg and 23,100 kg

Step 8: Summary and Conclusion of the cost comparison calculation for Scenario 2: In Scenario 2, in most cases the motorised tricycle seems to be the most cost effective solution. The longer distances decrease the advantage of the donkey cart due to the penalty of low speed and therefore high labour costs. While this is also favourable for the pickup truck, the relatively low amount of matter to be transported cannot cannot compensate the high CAPEX of the latter. Gasoline prices do not have much of an influence on the end result when it comes to choosing an option. Only at gasoline prices of double of the current levels and a low amount of materials transported, the donkey option can be more cost effective than the tricycle. The pickup truck, as before, remains the most expensive variant.

4.3.3 Scenario 2b: Longer distances, compost delivered to customer at a distance

Scenario 2b is the same as Scenario 2 with the longer distances to the customers. However, in addition it is assumed that the compost also has to be transported to the customer when it is ready. This is a likely scenario, for instance if MEWAREMA was to find one major client for its compost, such as a big agricultural producer, to which it would have to deliver. It is estimated that the producer is situated at 20 km from the treatment facility. A summary of the assumed variables can be found in Table 12. Please note that while the donkey cart option is still listed and compared, de facto the donkey cart is not a suitable option for pulling such a big weight over 40 km in one trip. Therefore the following calculations and numbers regarding the donkey are unrealistic by default and only shown to give a very rough idea of the effects of using a very slow vehicle.

Context for Scenario 2b	
Variable:	**Value:**
Personnel costs per worker per diem (8h):	342 KES
Gasoline costs per litre:	115 KES
Distance to client:	20 km
Average load per vehicle per trip for delivering compost:	100 %
Time for various things when delivering compost:	180 minutes
Average distance to customer from treatment area:	4 km
Distance between two customers on a trip:	0.4 km
Time required per customer:	10 minutes
Time required for unloading and various tasks per trip:	70 minutes
Average % load per vehicle per trip:	80% full
Minimum faeces transported per year:	6,700 kg
Minimum urine transported per year:	12,970 litres
Size of container:	50 kg / 50 l
Average distance to customer organic waste:	4 km
Amount of organic waste per year:	13,400 kg
Amount of compost producer per year:	14,070 kg

Table 12: The variables describing Scenario 2b. Values assumed.

Scenario 2b, Stage II: Actual cost comparison calculation

Step 4: Identification of the costs: This step is the same as in Scenarios 1 and 2.

Step 5: Methods of mathematical finance for comparison between present value costs and yearly costs: Table 13 and Table 14 show an overview over the costs assuming a compost production of 14,070 kg, a real interest rate of 5 %, a lifetime of 10 years, gasoline costs of 115 KES per litre and a per diem salary of 342 KES. As the CAPEX are the same as before, they are not repeated in Table 13. In Table 14 the costs are shown as present value costs and as yearly costs.

Costs of transport options			
Option:	**Donkey Cart**	**Tricycle**	**Small Truck**
OPEX:			
Personnel:	129,470 KES	54,395 KES	18,302 KES
Material and Energy:			
Gasoline:	-	14,266 KES	12,327 KES
Water/Food per year:	242 KES	-	-
Services:			
Yearly Maintenance Vehicle:	-	15,000 KES (= 15% of CAPEX)	67,500 KES (= 15% of CAPEX)
Yearly Maintenance Cart:	2,791 KES (= 7% of CAPEX)	-	-
Public	-	3000 KES	9000 KES
Total OPEX:	132,503 KES	73,010 KES	107,129 KES

Table 13: Scenario 2b: General overview of costs or consumption of the different transporting options considered

Net present costs and yearly costs			
Net Present Costs over 10 years at real interest rate of 5 %			
	Donkey Cart	**Tricycle**	**Pickup Truck**
Total CAPEX:	58,100 KES	100,000 KES	450,000 KES
OPEX for lifetime of 10 years, discounted:	1,023,161 KES	646,009 KES	827,219 KES
Total net present costs:	1,081,260 KES	746,009 KES	1,277,219 KES
Converted into yearly costs at real interest rate of 5 % over 10 years			
CAPEX converted into yearly costs:	7,522 KES	12,947 KES	58,264 KES
Total OPEX per year:	132,503 KES	73,010 KES	107,129 KES
Total costs per year:	140,025 KES	85,957 KES	165,393 KES

Table 14: Comparison of net present costs and yearly costs over 10 years

Step 6: Comparison between present value costs and yearly costs: In this scenario, the tricycle seems to be by far the most cost effective solution. The results of the donkey cart is to be ignored since, as described, it cannot be used for this scenario as the distances are too long. It is only shown indicatively and not taken into consideration for the actual results.

Step 7: Sensitivity Analysis: As in the previous scenarios, the results of Scenario 2b will be tested against fluctuations of three variables: real interest rate, price of gasoline and price of labour.

How much would the transporting costs be affected with changes in the real interest rate and what would be the consequences on the final results? As seen in Figure 18, as with the other scenarios, the real interest rate does not seem to have an impact on the results.

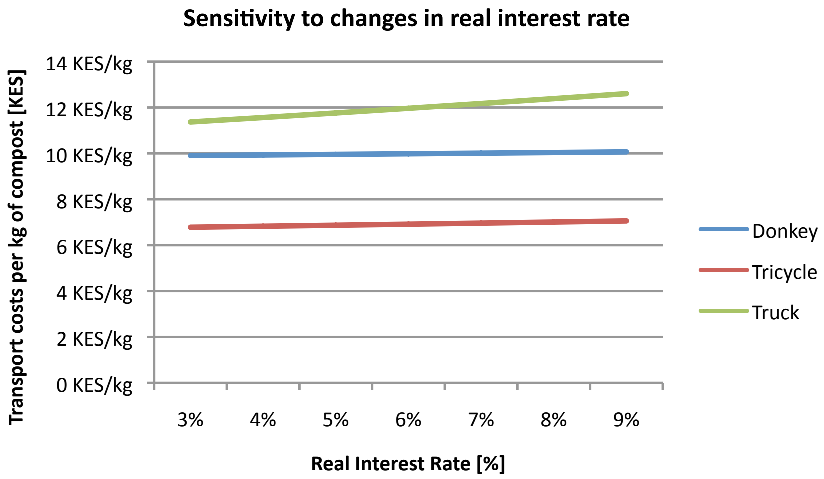

Figure 18: Scenario 2b: Sensitivity Analysis for real interest rates between 3 % and 9 %

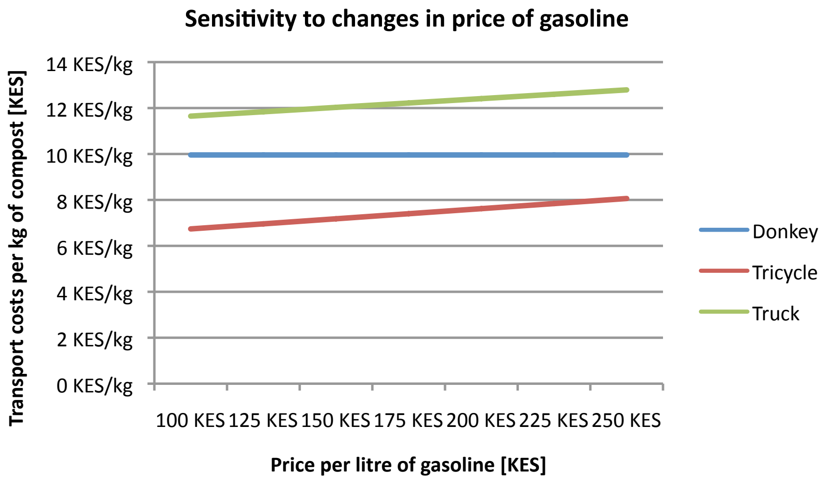

Figure 19: Scenario 2b: Sensitivity Analysis for the price of gas between 100 KES and 250 KES per litre (current: 115 KES)

Figure 19 shows the impact of fluctuations of the price of gasoline. As the donkey cart is not considered, both the motorised tricycle as well as the pickup truck are impacted by growing gasoline prices as reflected in the costs per kg of compost. However, in this scenario this does not have an impact on the outcome of the cost comparison.

As for the sensitivity of labour costs, Figure 20 shows the development of the prices of the three different options considering wages between 250 KES and 450 KES per day. Not taking into account the donkey cart, as both the tricycle and the pickup truck demand relatively little labour, while increasing labour prices decrease the difference between the costs of the two options, the end result is not affected.

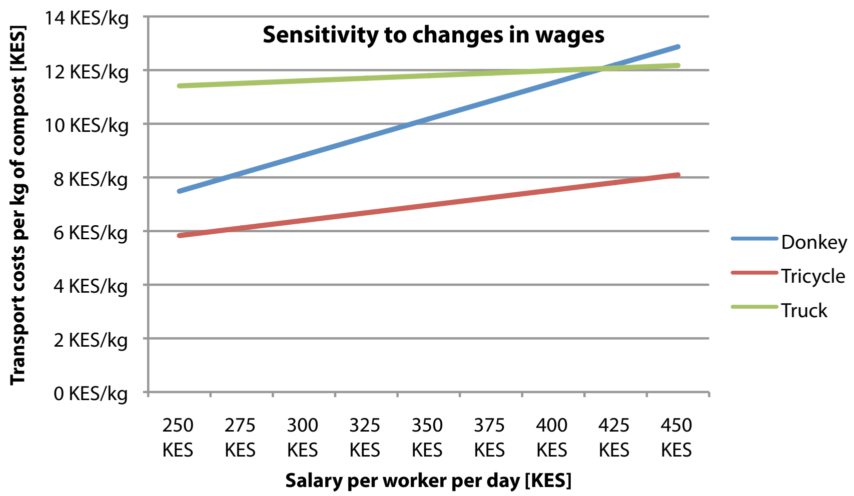

Figure 20: Scenario 2b: Sensitivity Analysis for per diem wages between 250 KES and 450 KES (current: 342 KES)

Considering only the tricycle and the pickup truck, in the given scenario none of the above tested factors seem to be decisive. Instead, it would seem more interesting to see at which point the amount of matter to be transported would be sufficiently high to achieve a critical value favouring the pickup truck over the tricycle.

The results of this analysis are shown in Figure 21 for labour costs between 250 KES and 500 KES per diem (standard: 342 KES) and a yearly amount of compost produced between 13,600 kg and 46,200 kg. Without changes in labour or gasoline prices, in this scenario at an annual production of about 40,000 kg of compost the pickup truck would become the most cost effective option.

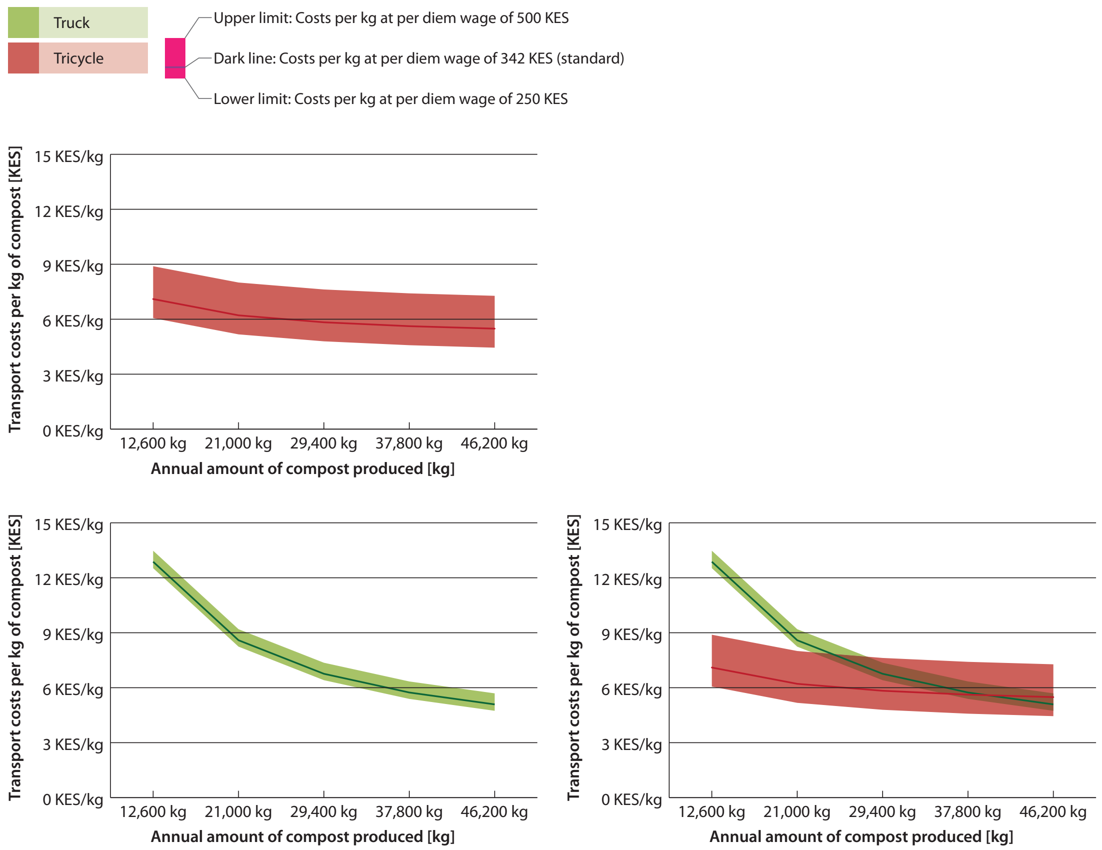

Figure 21: Scenario 2b: Sensitivity Analysis for costs per kg of compost produced for per diem wages between 250 KES and 500 KES at an annual compost production between 12,600 kg and 46,200 kg

Step 8: Summary and Conclusion of the cost comparison calculation for Scenario 2b: The much longer distances for delivering the compost to the customer requires a motorised vehicle. Already for technical reasons the donkey cart cannot be an option, if both the collection as well as the delivery is done by the same vehicle. Still, given the relatively small amount of material transported in the scenario, the tricycle seems to be the most cost effective option according to all graphs in the sensitivity analysis. However, not only is the pickup truck much less depending on labour costs, the costs per kg also decrease significantly as production increases while the increase of the economies of scale for the tricycle are much less pronounced and seem to stagnate after a certain production of compost has been reached. Still, for a smaller customer base, the tricycle seems to be the most cost effective option.

5 Discussion

Question 1: What method can be applied to calculate and compare the costs of delivering collection and treatment services for human excreta in the local context of Nakuru, Kenya?

Answer 1: The methods as suggested by the LAWA guidelines work in principle as the mathematical formulas and the concepts used are of general value. However, in reality the LAWA guidelines assume stability, continuity and much knowledge about average values of costs, efforts and life times of investments. Considering that the LAWA guidelines calculate over much longer time spans than assumed for example in Nakuru, this might not pose too much of a problem, but it does decrease the accuracy and dependability of the results.

The LAWA guidelines use a bottom-up approach for calculating the costs. In a context such as Nakuru, this poses a problem due to the lack of data. There is now enough knowledge about the efforts and costs factors and that there are is not enough top-down data available from comparable situations. Therefore this decreases the overall reliability, not of the methods used but of the results.

Question 2: In the case of Nakuru, what seems to be the most cost effective solution transport for MEWAREMA?

Answer 2: As shown in Scenario 1, in the current situation, the donkey cart seems to be the most cost effective option. As service is expected to increase rather slowly, there is no indication that in the first 5 years of service this would change, even if factors such labour were to become more expensive. However, Scenarios 2 and 2b also show that this results seems to be true mainly for the combination of relatively little throughput and short distances. If the evolution of the business follows as foreseen then by the time a different transportation solution might be more cost effective, the current one would probably already be at its end of life and require reinvestment anyway.

Question 3: Sensitivity Analysis: How would certain changes in parameters influence the results?

Answer 3: In the current situation of Nakuru, a change of parameters such as labour costs, real interest rate or the price of gas would not have an impact. In a different scenario however this might be very much the case as the calculations for Scenario 2 and 2b have shown. Interest rate seems in all Scenarios to be the least important factor as it affects mostly the options with high investment costs which however already are more expensive due to effects such as maintenance and the CAPEX itself. Gasoline prices can have an influence in a given scenario when all other variables considered for example the donkey cart and the tricycle are close as it can be the case in Scenario 2. It does however not seem to be decisive in the choice between different motorised vehicles. Labour seems to be the most decisive factor but, at least in the examples of this thesis, decreases as the investment costs of an option increases. For the choice between tricycle and donkey cart it seems to be decisive and has a very big impact on the transport costs per kg of compost produced.

Question 4: How reliably can such a calculation estimate the costs and what are the main problems restricting accuracy?

Answer 4: The reliability depends a lot on the availability and the quality of the input data. Given the many uncertainties, it is probably extremely difficult to assume correctly the costs for collection and transport per kg of compost produced with a bottom-up approach. However, the results of the cost comparison procedure should not be affected too much by this, especially if the sensitivity analysis is taken into account in the decision taking. There is probably a high chance that, despite assumptions and vague data, such a cost comparison procedure can be an important help in choosing a cost effective solution. Either way it is certainly helpful in discovering the impact of cost factors.

Summary: Unsurprisingly, the results of the calculations indicate that different scenarios favour different means of transportation. The calculation of Scenario 1 seems to confirm that, in the current situation, the donkey cart is the best solution from a cost perspective. This results seems to be rather safe as in the calculations it is not affected by the results of the sensitivity analysis. Scenarios 2 and 2b on the other hand show that the donkey cart is only a viable option if the distances are short and the amount of matter to be transported restricted. Increasing distances to the customers require much more labour for the donkey cart than for the motorised options due to the slowness and, in comparison to the truck, the restricted load. Already at relatively small increases can make the donkey more expensive than the motorised tricycle. Certainly such changes increase the impact of fluctuations of parameters such as labour costs on the final results as seen in the sensitivity analysis. It was interesting to see that however neither changes in price of gasoline nor in real interest rates seem to have an important impact in either of the scenarios.

The shortcomings of this thesis are certainly the lack of data available, as cost calculation procedures require a bottom-up approach of calculating the costs. However, most data available was top-down data. Therefore, the initial idea of a bottom-up approach for the calculation of the costs proved to be very difficult to implement. Reasons for that are the lack of data available on the processes themselves, which is why for calculating the time efforts assumptions had to be used. This of course falsifies the results, especially since, as mentioned, labour is a very important part of the costs. Generally speaking, many factors contribute to the difficulty of finding reliable average values for the processes and efforts.

Factors such as the quality of the roads or height differences of the terrain, which have an influence on the time required to travel, were not considered in the calculations or the decision process. Neither were other factors such as the possible costs for disposing of excess urine that is not used in the co-composting process. As far as the investment options are concerned, one of the major concerns was the fact that the LAWA guidelines assume standard investment objects with standard costs and standard lifetimes. In the context of this thesis however, it was not possible to follow this approach. Lifetimes vary, not all vehicles might be bought new, given the circumstances the investments may break down earlier or on the contrary be used much longer than it would be assumed. Therefore, as said earlier, it is especially important to make case-by-case assumptions regarding those factors when trying to estimate the costs instead of relying on general assumptions. The results of this thesis show a trend, but at the same time the assumptions included in the calculations disqualify the calculated costs for being used "as is".

Further research should concentrate on the analysis of the processes involved in transport, collection and treatment. As seen, all those factors rely heavily on labour. While it is relatively easy to get data on daily labour costs, the difficulty lies in knowing where how much labour is needed. This information would be required to scale costs and to be able to compare different options, especially if no or only very little top-down data is available. Only with sufficient information an approach more similar to the LAWA guidelines with its database of standard values can be followed.

6 Conclusion

The LAWA guidelines cannot be applied exactly as they are due to the many uncertainties, they do however provide important concepts and principles in how to implement a cost calculation and comparison procedure in general. When precautions are taken and a reduction in predictability is acceptable, then this approach can be an important help in finding the most cost effective solution.

Projects such as ROSA are supposed to bring sustainable results without continuing external support. To achieve this, it is essential for collection, transport and treatment services work as required by the infrastructure installed. If those services are not assured by public bodies, then the service providers must have some sort of reachable gains from delivering their services. Otherwise the service will most likely stop and force the infrastructure break down and even become harmful. The costs involved in collection, transport and treatment are not high for European standards, but high enough for local standards to make it essential to deliver the services using the most cost effective options. Despite all the shortcomings mentioned before, a cost calculation method can help to do so. Therefore, applying those principles should be an essential part of establishing such infrastructures and the services involved from the beginning with a view to establishing sustainable services.

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