Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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Decentralised Composting in Developing Countries

Financial and Technical Evaluation in the Case of Asmara City

Diploma Thesis of Christian Müller

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Eawag, Dept. Sandec
P.O. Box 611
Überlandstrasse 133
8600 Dübendorf
Switzerland

Diploma student:

Christian Müller
Tel: +41 (61) 941 10 46 muellerchristian@hotmail.com

Supervisors:

Susanne Kytzia (ETH)

Silke Drescher (Sandec)
Tel.: +41 (0)44823 50 25 **silke.drescher@eawag.ch**

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List of Abbreviations

AD	Administration
AMR	Administration of Maakel Region
BC	Block collection
CC	Centralised composting
DC	Decentralised composting
EMIS	Environmental Management Information System
ISWM	Integrated Sustainable Waste Management
LF	Landfill
MFA	Material Flow Analysis
MSW	Municipal Solid Waste
NEMP-E	National Environmental Management Plan of Eritrea
Nkf	Nakfa: Eritrean currency
PCA	Process Cost Accounting
SANDEC	Department of Water and Sanitation in Developing Countries
SC	Skip collection
SS	Street sweeping
SU	Sanitation Unit
SWM	Solid waste management
TP	Transfer point
UWEP	Urban Waste Expertise Program
WHO	World Health Organisation

Abstract

Decentralised composting is one possible approach to treat, recover and reuse the organic fraction of the solid waste. In contrast to centralised systems the waste is treated close to the source of generation. Therefore the amount of waste which has to be transported to the disposal sites can be reduced significantly. The reduction of waste leads to cost savings in transport and disposal. But until now specific data on such cost savings is not available. Nevertheless essential information is needed for strategic planning and informed decision making by the responsible authorities.

The evaluation presented in this study applies a combined approach of Material Flux Analysis and Process Cost Accounting. This approach enables the comparison of different solid waste management (SWM) systems regarding waste flows and costs. With the software tool Umberto 5.0, the solid waste management system of Asmara, the capital city of Eritrea, was modeled. Furthermore, different SWM scenarios were analyzed and the implications on the current system determined.

The following SWM systems were evaluated:

- The current SWM system, where the solid waste is collected by the sanitation unit and disposed of at the municipal landfill.
- Centralised composting system, which consists of one large composting plant with a capacity of 180 tons of incoming mixed waste per day. The plant is located closeby the municipal landfill processing all waste collected.
- Decentralised composting system 1, which consists of 60 small plants with a capacity of 3 tons of incoming mixed waste per day each. The plants process all waste collected by the municipality
- Decentralised composting system 2, which consists of 36 small plants with a capacity of 3 tons of incoming mixed waste per day each. The plants do not process waste coming from street sweeping as it is potentially contaminated with heavy metals.

The results of the study indicate expenses for the current SWM system of nearly 10 Mio. Nakfa. This corresponds to 25 Nakfa (1.7$) per capita and 225 Nakfa (15$) per ton of waste.

If implementing composting the overall expenses increase significantly. In the case of the centralised and decentralised system 2, the cost increase is about 25%. For the decentralised system 1 the results show an increase of 35%.

The cost increase is due to operation of composting plants. But in the decentralised systems the high plant operation costs are partly compensated by a significant cost reduction in waste collection and transport.

The results are based on a transport distance to the municipal landfill of 6km. But the study demonstrates that the longer the distance the more viable it is to implement decentralised composting. In a distance of about 17km to the landfill, the expenses for the current system and the decentralised system 2 are equal.

The salary costs are the dominant part in the cost structure of decentralised composting and therefore represent the potential of employment generation. In addition, as mainly unskilled labour is employed, decentralised composting can be seen as a feasible approach towards poverty allevation in developing countries.

1. Introduction

1.1. Solid Waste Problem in Developing Countries

1.1.1. General Situation

Solid waste management is one of the challanges facing every urban area in the world. An aggregation of human settlements has the potential to produce a large amount of solid waste which has to be collected and treated.
In developed countries, the collection, transfer and disposal is satisfactorily organised by municipal governements. In contrast, for many under-developed nations the municipal solid waste management (MSWM) has become a major problem, considering human health, environmental and economical aspects. The problem in many developing nations is strongly related to rapid urbanisation. More than one third of the population in many developing countries is urban and in many African nations the growth rate of urban areas exeeds 4% (Senkoro 2003).

Municipal solid waste is broadly defined as garbage, refuse, and other solid waste from residential, commercial, industrial and community activities that are gathered for collection[1]. Generally, sewage sludge and human waste are regarded as liquid waste and are thus, not considered as MSW (Zerbock 2003).

The generation of solid waste in developing countries is increasing. Consequently, the demand for collection service is increasing continously. The increase of municipal tax and fee revenues is not keeping balance with the population growth and with service expenses. This is due to the fact that mostly poor people from rural areas are migrating into city's agglomerations unable to contribute to municipal revenues. Despite of their smaller waste generation due to a lower level of consumption, their demand for service exists.

1.1.2. Logistical & Financial Challanges

Existing waste management systems are not capable of handling the generated amount of waste. Collection, treatment and disposal of the increasing amount of solid waste are becoming more demanding.
Due to growing agglomeration areas, transport and collection efficiency is decreasing. Apart from increasing municipal traffic, transport distances are becoming longer and thus, the collection of waste is becoming more time-consuming (Zerbock 2003). Declining collection efficiency is connected with higher expenses. Hence, municipalities have raising problems in meeting the financial demand of MSW management. The increase of tax and fees is not likely to be a long-term solution as residents are not able or willing to pay more for poor service.
However, the rapid urbanisation leaves little time for accurate planning of a new MSWM.

1.1.3. Human Health Risks & Environmental Issues

Generally, handling solid waste is associated with some human health risks. Especially, in many developing countries the risk is significantly higher and related health problems are common and widespread. The problems can be classified into four main categories (Cointreau 1982).

- Municipal solid waste contains human feacal matter. In developing countries, its presence is likely to be related to inadequate sanitation infrastructure and management.

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[1] Source: www.recyclethis.org

- Most solid waste contains some industrial waste, which can pose significant health risks. Despite existing regulations and separate service for industrial establishment, at least on a casual basis, small-scale enterprises are likely to use the municipal solid waste system for disposal.
- The decomposition of organic waste is considered as potential danger for human beings, as well as for the environment. Especially, in developing nations, where open dumps are the common disposal sites, decomposition of waste can release chemical consituents into drainage and atmosphere in form of gas emissions and leachate water.
- Burning of solid waste emitts hazardous smoke which creates extensive pollution in many cities of developing countries. Apart from intentionaly burned materials, smoke development is mainly occurring due to sponaneous combustion of dried organic matter. Continous generation of methan gas by anaerobic decomposition of organics within the landfill is basis for fire.

1.2. Strategies for Improvement

Considering the large number of specific problems in various municipal solid waste management systems, solution finding is a common issue confronting municipalities or private responsibilities. Keeping the system running as efficiently as possible individual problems are locally fixed. In the short term, this is likely to be a good approach. But in the long term a set of sustainable solutions is required. Thus, the individual issues have to be approached in a broader and more integrated way. Nowadays community- and regional-specific issues and needs are tried to be considered. Thus, integrated and more appropriate solutions are implemented.

An intergrated waste management is a way of managing water supply and sanitation services which focuses not only on certain aspects as for example technology, but takes into account also the whole system, including social, economic, environmental and other aspects (Egger 2005).

The concept of an integrated solid waste management (ISWM) has been articulated and refined in the Urban Waste Expertise Programm (Scheinberg 2001). Basically, it is seen as an analytic framework for understanding waste management systems and as an assessment methodology for predicting feasibility and sustainability. Furthermore, the ISWM can be considered as a description of a urban development process (UNEP 1996).

ISWM approaches are emphasising waste reduction and appropriate disposal options (Zerbock 2003).

Reduction of waste can be achieved either by generation of less waste or by increasing waste material recovery. Waste generation is, probably, more a function of individual habit and affluence and is thus hardly controlled by municipalities or private insitutions. Several methods, such as raising awareness of consumers, are more effective if done on a national level, but result in very cost-intensive campaings and are thus difficult to realise in developing countries.

Therefore, waste recovery is a more appropriate option of waste reduction in many developing countries (Diaz, Savage et al. 1996). Reuse and recycling of inorganics is already practised by the informal sector[2], which is often part of SWM systems in developing countries (Zurbrugg 2002). A part from strategies toward enhanced recycling of inorganic materials, the reuse of organics can be seen as an integrated approach in developing countries.

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[2] part of economie characterised by private, usually small-scale, labour intensive, largely unregulated and unregistered manufacturing or provision of service (Coad, A. Part IV: List of Terms and Definitions. Guidance Pack: Private Sector Participation in Municipal Solid Waste Management.

1.3. Composting as an Approach

In many developing countries the organic fraction of solid waste is more than 50% (Hoornweg 1999); (Drescher and Zurbrugg 2005). Regarding the high content of organics, composting is an option to treat and reuse the biodegradeble fraction.

"Composting is the biological decomposition of biodegradable solid waste under controlled predominantly aerobic conditions to a state that is sufficiently stable for nuicanse-free storage and handling and is satisfactorily matured for safe use in agriculture." (Diaz, Savage et al. 1996).

In general, there are three scales at which composting has been implemented (Zerbock 2003); the residential level, the decentralised community level, and the municipal-wide centralised level. Often, centralised composting units are huge, high-technology plants requiring high capital investments. Decentralised units are small-scale labour-intensive plants, whereas residential unit are constructed for private purpose (Drescher, Zurbrugg et al.). However, the implementation of composting in developing countries has many potentials that are presented as follows.

1.3.1. Potentials of Composting

In the following sections major potential, as well as spillover effects of composting are presented.

Use as a Soil Conditioner and Fertiliser

Generally, the use of mature compost, the final product of a composting process is an evironmentally sound recycling method (EPA 1995) and has positive influence on plant growth. The regulated application of compost on soil serves as soil conditioner improving the soils structure, texture or drainage and as fertiliser due to a high content of nutrients (Diaz, Savage et al. 1996).

Savings in Transport Costs

Decentralised composting reduces transport costs due to reduction of waste going to the disposal site (Drescher, Zurbrugg et al. 2005). The reduced waste stream leads to a declining demand for transport capacity. Considering a vehicle fleet, the transport of less waste results in savings for fuel. In the long-run, the purchase of vehicles can be prevented or postponed and thus, additional savings can be expected.

Extension of Landfill Lifespan

Generally, composting extends the lifespan of landfills (Drescher, Zurbrugg et al. 2005). When done on a municipal level, the reduction of waste going to the landfill is significant. This leads to less waste disposed of at the landfill and therefore extends the fill time. According to this, expected investments for landfill expansions can be postponed and thus futher costs can be saved.

Generation of Employment

Implementation of composting is coupled with generation of employment (Drescher, Zurbrugg et al. 2005). Handling and treating of organic matter, as well as operation of plants requires labour. The reduction of labour for transport of waste can not meet the demand for operation of compost facilities. Thus, additional labour has to be employed.

Reduction of Greenhouse Gas Emissions

Composting reduces greenhouse gas emissions by avoiding a later degradation of organic matter within landfills. In particular, anaerobic decomposition of organic waste within landfills generates greenhouse gases mainly methan and carbondioxide (about 50% each, (Lüthi 2005)). Under controlled aerobic conditions methan emissions, having a high greenhouse potential, are significantly reduced (Stegmann 1995) or do not exist, where the carbon dioxide emissions per ton of waste are less (EPA 2002). Due to the potential of reducing greenhouse gas emissions implementation of composting is likely to be accepted as Clean Development Mechanism (CDM) project. The acceptance as a CDM project leads to international fundings (Lüthi 2005).

Reduction of Groundwater Pollution

Composting reduces groundwater pollution on disposal sites by avoiding a later degradation of organic waste within uncontrolled disposal sites. Degradation of organic waste generates leachate with highly concentrated organic substances. They cause taste and odor problems, as well as oxygen depletion of the groundwater. In addition, these organics can serve as co-substrates for microorganisms that can facilitate the conversion of hazardous chemicals to even more hazardous forms. Additionally, these organics emerging from organic waste serve as complexing agents for heavy metals which enable their transport in groundwater systems (Jones-Lee and Lee 1993).

1.3.2. Limitations of Composting

Despite of having a huge potential, the feasibility of composting as a sustainable method of organic waste recovery is still questioned in developing countries (Zurbrugg, Drescher et al. 2004). Consequently, composting is not widespread and this is due to a number of reasons (Hoornweg, Thomas et al. 1999).

In the recent past, a lot of composting projects failed due to oversized, overmechanised, centralised plants not suitable for the local conditions. The failure was mostly due to limited revenues from compost sale, which were not meeting the high investment and operation costs.

Generally, maintanance and operation of composting plants was done inapproppriately. Training of labour was often neglegted and thus knowledge for biological process requirements, as well as adequate operation of facilities was missing. Insufficient pre-sorting of incoming waste lead to a poor quality of feedstock for composting yielding poor quality compost.

Furthermore, there was a lack of markets for the final compost product. Little experience was resulting in poor marketing plans beginning at the moment of implementation. Integration of various stakeholders, such as agricultural communities being the end users of the product was done insufficiently.

1.4. New Strategy

By looking at previous failures, projects were focusing more on technical and social issues, but the importance of finacial aspects and the availability of markets were often neglegted (Zurbrugg, Drescher et al. 2004).
Considering the concept of ISWM in low and middle-income countries decentralised composting is expected to be more viable. Some of the reasons are that decentralised composting systems:

- reduce the cost incurred for the collection, transport and disposal of waste
- reduce the volume of solid waste at the source more effectively
- are less technology dependent than centralised plants and thus, the level of specialised skills required is lower
- are more labour intensive and thus, generate employment
- invite lower capital and maintenance costs per plant than centralised options
- are well suited for the waste stream, climate, social and economic conditions
- require low cost, locally available materials
- enhance environmental awareness and community participation in source-separation

As already mentioned, decentralised composting has the potential to reduce costs for transport and for disposal. But until now, specific data on such financial and economic cost savings are not available (Drescher, Zurbrugg et al.). However, this data is important for strategic planning and decision-making by municipal authorities.

1.5. Objectives of Study

In the framework of this study, required information regarding financial aspects of centralised and decentralised composting systems are provided. The study describes one out of three case studies initated by Sandec (Department of Water and Sanitation in Developing Countries, Switzerland) on the economic evaluation of composting. The case study assissts in visualising the existent solid waste management system in Asmara (Eritrea) and in estimating cost changes achieved by implementing composting units. The results shall aid decision-making and strategic planning for investments and project development in integrated solid waste management of developing countries.

The specific objectives of this study can be summarised as follows:

- A model is developed based on the current SWM in Asmara which gives option to represent different SWM systems.
- Material flows within the current SWM-system of Asmara are assessed and visualised according to the material flow analysis methodology.
- Financial data corresponding to the current SWM system is collected and structured according to the existing SWM processes.
- Additional information on SWM-processes allows the modelling of relevant scenarios, such as centralised and decentralised composting, which serve as a basis for comparision with the current SWM-system.
- A sensitivity analysis is conducted identifying the main parameters in the model being relevant for the SWM system.

1.6. Study Hypothesis

The study hypothesis is based on the existing physical, as well as socio-economical situation in Asmara, Eritrea:

- Decentralised composting is seen as feasible appraoch towards sustainable development. The implementation of decentralised composting leads to a decrease of solid waste flow going to the municipal landfill affecting solid waste collection and transport. Based on that it is assumed that the increase of costs for operation of decentralised plants is nealy compensated by cost reductions for solid waste collection and transport.

2. Methodology

In this section different methods, as well as a tool are presented, which serve as key elements in the approach used in this study. Descriptions are kept brief and generally.

2.1. Methods & Tool

2.1.1. Material Flow Analysis

Material flow analysis (MFA) is a method to describe, investigate, and evaluate the metabolism of anthropogenic and geogenic systems. MFA defines terms and procedures to establish material balances of systems.

Basically, material balances are based on the law of conservation of matter. Due to this distinct characteristic of MFA the method is recognised as a decision-support tool in resource management, waste management, and environmental management (Brunner and Rechberger 2004).

In order to investigate systems, commonalities are defined which facilitate comparision of results from different MFAs. The terms and procedures to analyse and model material flow systems are determined enabling comprehension, reproducibility and transparency of flows and stocks in a system.

Before establishing a material balance a system has to be defined corresponding to the field of interest. A system is defined by determination of system boundaries. Unimportant aspects of the system are not aim of investigation and thus, they are excluded (Bundesministerium für Umwelt 1995).

According to MFA terminology functional units in the system are defined as processes. Basically, processes can be of natural or anthropogenic nature. For instance, transport, transformation or storage of materials is represented as processes. The storage of material is considered by definition of stocks.

Stocks are defined as material reservoirs within the analysed system. Stocks stay constant, increase or decrease depending on the accumulation or depletion of materials.

Processes are linked by so-called material flows. Material flows across system boundaries are defined as imports or exports.

As a central term, materials can be defined as goods. According to MFA terminology, the term good only includes materials as such. Energy, services or information are not considered as goods.

Basically, a MFA system comprises of a set of material flows, processes and stocks within defined boundaries (Baccini and Bader 1996).

2.1.2. Cost Accounting

Cost accounting is the essential part of business accounting. Apart from income determination and control of operational efficiency, planning, making offers and pricing are the most important tasks of cost accounting. Cost accouting thus forms the basis for entrepreneurial decisions and for finance-controlling[3].

Cost accounting involves the allocation of different types of cost to products or service performances. In case of manufacturing one single product, all costs accrued for administrative and construction work can be allocated to the same product.

In case of manufacturing two different products, the allocation of costs is more difficult. Product-related costs (direct cost) in construction can be allocated directly, whereas administrative overhead costs have to be randomised.

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[3] Source: http://www.umberto.de

In the following the cost types mentioned above are briefly defined:

- **Direct costs** are variable material and labor costs that can be directly traced and allocated to a specific unit of production[4]

- **Overhead costs** are costs that are not directly related directly to the type and quantity of products produced. A type of fixed cost[5].

Apart from direct and overhead costs, two other types of cost have to be discussed: fixed and variable costs.

- **Fixed costs** are costs that do not change with the level of production[6].

- **Variable costs** are the costs for a product which are associated with the number of units that are produced[7].

Basically, costs dependent on lot size are defined as variable costs. Theoretically, the relation between variable costs and lot size is considered to be linear. Thus variable costs are mostly considered as proportional.
In practice direct and overhead costs are frequently confused with variable and fixed costs. In fact, many direct costs are variable, but there are also exceptions.The yearly amount of depreciation (explained below) for a machine producing one specific product is considered as a fixed cost. Nevertheless, the allocation of costs to the product can be done directly. Similarly, some overhaed costs are variable, others are fix. For example, cost for energy, lubricants, salaries are considered as variable overhead costs, whereas depreciations, insurances costs are defined as fixed overhead costs. In Figure 1 the interconnection between direct, overhead, variable and fixed costs are shown.

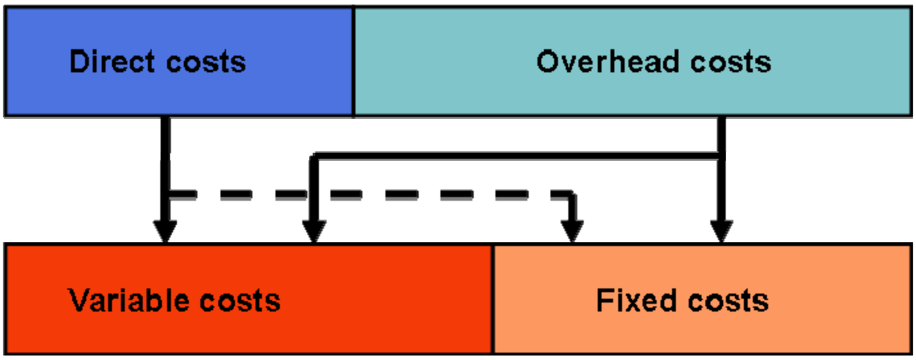

Figure 1*: Illustration of interconnection between direct, overhead, variable and fixed costs. Source: (Seiler 2005).*

Cost accounting in general tries to achieve two main targets. As a first intention costs have to be assessed and allocated to products and service activities according to a consumption-dependent principle. Secondly, aiming at cost transparency costs have to be allocated towards their responsible units. Usually these targets can be achieved by implementing three accouting steps (see Figure 2):

- cost type accouting
- cost center accounting
- cost unit accounting

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[4] Source: www.bridgefieldgroup.com/glos2.htm
[5] Source: www.agmrc.org/agmrc/business/gettingstarted/farmanalysisterms.htm
[6] Source: www.extension.iastate.edu/agdm/wholefarm/html/c1-05.html
[7] Source: www.ktec.com/sec_news/hs_busplan/definitions.htm

Cost type accounting involves the assessment and classification of costs according to their origin.

A cost center is defined as a unit locally or functionally distigiuished and responsible for cost generation. Administration for example, as a functional unit, can be defined as such. In cost center accounting generated cost are allocated to specific cost centers.

Cost units are products or services where costs finally can be allocated.

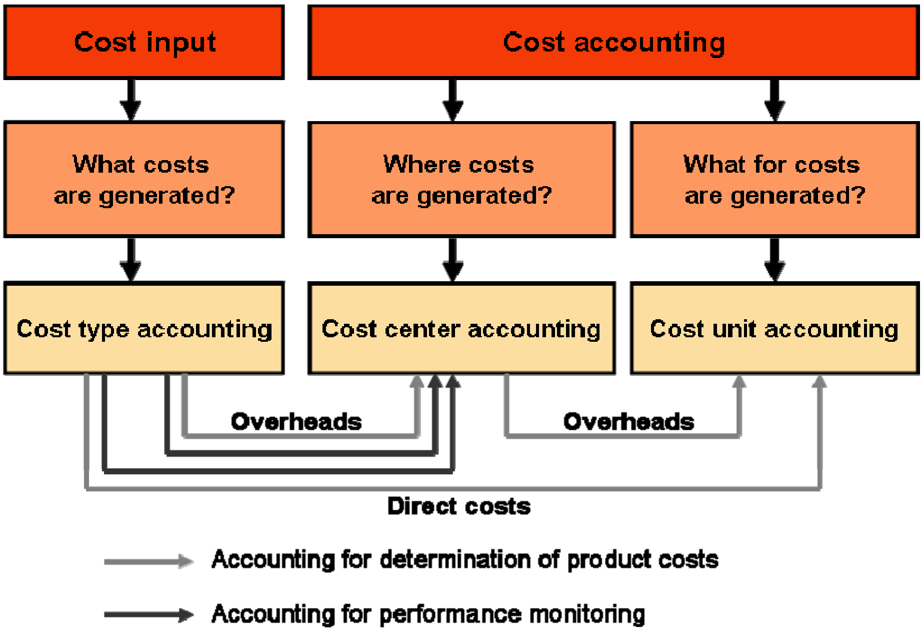

Figure 2*: Schematic description of cost accounting steps. Determination of product cost or performance monitoring leads to different cost accounting. Source: (Seiler 2005).*

Generally, the aim to determine original costs of products, in order to define the price of sale, can only be achieved considering imputed costs, such as depreciation and interest on capital.

The operation of a business' infrastructure results in a wear and tear of machines and other assets. Despite of not being a true expense, the wear and tear of assets is considered.

For instance, one-off expenses, such as for purchasing a long-lasting machine, are hardly to be allocated due to their non-operational character.

However, the use of such an asset for production purposes leads to a decline of value. Thus, the decline of value is accounted as depreciation. In the following the calulation of depreciation is presented according to the straight-line method. The method is based on the assumption of proportionality between decline of value and time of use. Depreciation expenses in a certain period are calculated as follows (Seiler 2005):

$$D_t = \frac{(P - S)}{n}$$

D_t: Depreciation expenses in a certain time period t
n: Lifespan of asset
P: Purchase value of asset
S: Salvage value of asset

In order to evaluate the true cost of service or production, the interest on capital need to be considered. The interest on capital is seen as a missed return. For instance, the money spent for an operational asset could have been saved in a bank. The bank's interest rate gives additional value which is missed if investing into business (Rollwage 2005). Basically, the interest on capital is defined as opportunity cost[8]. In the case of purchasing an asset, for calculation of the interest on capital mostly interest rates of banks are utilised (Seiler 2005). In the following the formula for calculation is presented:

$$I = I_r \cdot \frac{(P + S)}{2}$$

I: Expenses for interest on capital
I_r: Rate of interest
P: Purchase value of asset
S: Salvage value of asset

In practice there is not only one form of cost accounting, but a variety of different possible approaches. In the following, one approach, the method of process cost accounting, is specified.

Process Cost Accounting

In the recent past, cost structures in industries started to change significantly. Overhead costs started to increase compared to direct costs due to automatisation of production, increase in complexity of fabrication, networking with distributors or opening of global markets. In science and practice traditional cost accounting systems were questioned. It was argued, especially in the United States, that cost allocation is not done consumption-dependently and due to the increase of overhead cost condidered as unsufficiently. Consequently, in the eighties Activity Based Costing[9] was developed. In the German-speaking part this way of accounting was then implemented as Process Cost Accounting (PCA).

Generally, in PCA the accounting steps as known from traditional cost accounting are retained. In particular, PCA is based on the concept that the activities of a company are categorised into processes and that operational procedures regarding material and energy flows, including corresponding costs, are made transparent (Wagner and Enzler 2005).
The costs are basically generated when activities are performed. The activity performed on each unit is standardised where a continous mass production or service is involved[10].
As a principle of PCA, resources are assigned to activities, which are themselves assigned to cost objects.
Due to a casual relationship, specific factors, called cost drivers, enable the recording of activities. For instance, motor-driven waste collection generates costs due to comsumption of fuel and other resources. The costs for waste collection strongly depend on the number of collection trips required for different cleaning purposes. Thus, the number of trips can be considered as a specific cost driver.
Normally, cost drivers determine activities of various cost centers. Therefore, it is reasonable to summarise these activities as major processes influenced by the same cost driver (Seiler 2005). With the implemention of cost drivers, overhead costs depend more on activity-related factors, such as size of order or complexity of the product. Thus, the costs are allocated more comsumption-dependent.

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[8] Opportunity costs: The cost of using a resource based on what it could have earned if used for the next best alternative (www.extension.iastate.edu/agdm/wholefarm/html/c1-05.html).
[9] Explanation of ABC: http://www.pitt.edu/~roztocki/abc/abctutor/
[10] Source: www.maaw.info

2.1.3. Environmental Management Information System

An Environmental Management Information System (EMIS) is a systematic approach to ensure a well organised management of environmental activities. It is a management tool to process data according defined procedures evaluating environmental impacts of organisation's actions. In the following a specific EMIS is presented.

Software-tool: Umberto 5.0

Umberto 5.0 is the current version of a software-tool developed by the Institute for Energy and Environmental Research Heidelberg Ldt. (IFEU) in cooperation with the Institute for Environmental Informatics Hamburg Ldt. (IFU). Umberto is an EMIS which facilitates input, management and visualisation of data.

Based on material and energy flows, costs of processes and materials can be allocated and displayed. A combination of material flow systems and allocated costs serves as option to identify improvement potentials in production and service operations, taking ecological and economic aspects into account[11].

The calculation of material flows in Umberto is based on the theory of Petri Nets according to Carl Adam Petri. A Petri Net is a graphical and mathematical modeling tool. It consists of places, transitions, and arcs connecting them, as seen in Figure 3 (Heubach 2002).

***Figure 3**: Illustration of Petri Net elements, such as transition, arc and place. Source: (Heubach 2002).*

Transitions can be seen as processes, where materials and energy are transformed. In each transition the balance of in- and output is described. Transitions consist of specifications that define the relationship beween in- and output flows. Furthermore, as an additional feature costs can be allocated using transition specific cost drivers. Additionally, parameters can be determined defining the process' attribute.

Within the Umberto 5.0 transitions are symbolised as squares.

Places describe points in the net where material and energy is stored or generated. Places, symbolised as circles, represent various functions, such as:

- Input-places, where materials enter the system.
- Output-places, where material leave the system.
- Places, which serve as connection between transitions.
- Places, which serve as storage within the system.

Arcs, as a further unit of Petri Nets, establish a relationship between transitions and places. They represent the material or energy flow toward defined directions. Basically, arcs are symbolized as arrows.

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[11] Source: http://www.umberto.de

Material Flow Model in Umberto 5.0

The material flow model is decribed using the three elements of Petri Nets (Schmidt and Keil 2002). The models boundaries are definded with in- and output places. Transitions are seen as the key element for modeling due to their specifications being responsible for calculation of material transformations.

On a central material list materials are managed. Materials listed can be allocated to material or energy flows.

Apart from specifications, reference flows have to be defined being the basis for calculation of material flows. Calculated output flows are given to the following transition until the system is calculated. Inconsistencies in specifications have to be avoided.

In oder to allocate costs in Umberto, costs are classified into direct costs for materials and process-related costs. Process-related costs are classified into proportional costs and fixed costs. After allocation, costs are structured hierarchically in a cost plan according to cost types.

Direct costs depend on material flows and defined prices for materials. Process-related costs are allocated within transitions using cost drivers as a link between cost and material flows (ifu and Ifeu 2005).

2.2. Approach

The appraoch used in this study consists of a combination of Material Flow Analysis (MFA) and Process Cost Analysis (PCA) for evaluating the viability of composting concepts. The MFA component serves as a basis to visualise waste flows and processes (e.g. temporary storage, transportation, treatment or disposal) of Asmara's solid waste management (SWM) system. Based on the existing SWM system, future treatment scenarios are modelled and calculated. In order to determine the economic aspects of centralised and decentralised compositng and its effects on Asmara's solid waste management system, three composting scenarios are compared with the current system (baseline) as shown in Figure 4.

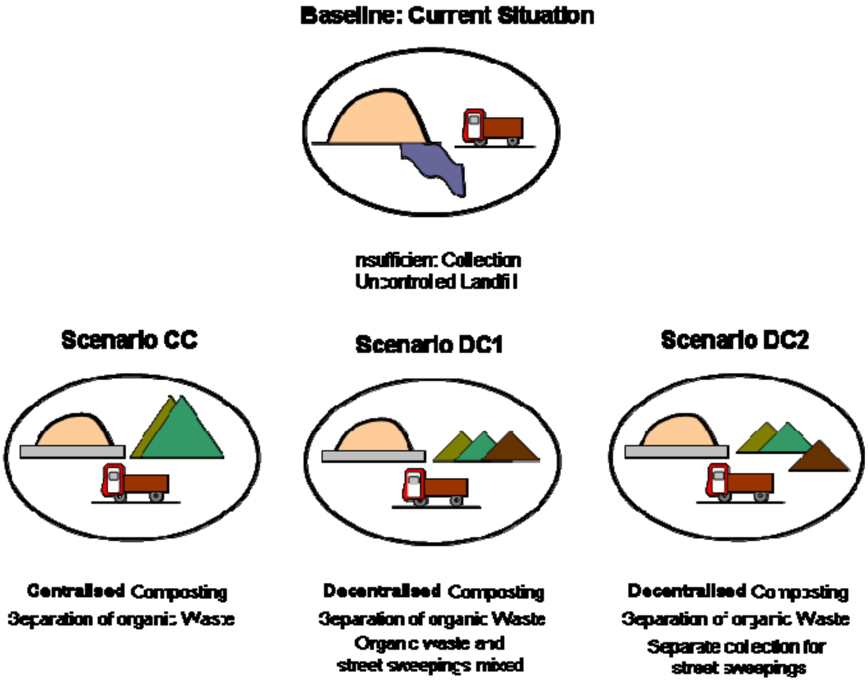

***Figure 4**: Illustration of the baseline and the three scenarios being evaluated. In all scenarios, which are based on the current system, composting plants are implemented.*

This approach allows the visualisation of changes in waste flows and costs induced by composting processes. The PCA serves as a method to allocate fixed and variable costs to defined processes in the system. Thus, cost-revenue balances for the described SWM system were calculated. The combination of physical and financial data assists the decision makers in predicting the effects of new SWM strategies (e.g. organic waste recycling) beyond the typical financial considerations (Drescher, Zurbrugg et al. 2005).

2.3. Data Collection & Processing

Data collection for this thesis was done in 2004 by local researchers (Tedros Kubrom and Sirak Mehari, College of Agriculture in Asmara), assissted by a swiss researcher (Matthia Wegmann, Swiss Federal Institute of Science) in co-operation with municipal authorities in Asmara and Sandec. The final report of this study (Kubrom, Mehari et al. 2004) was the main basis of this thesis.

The author's personal experience in Asmara during an internship of 4 month in 2003 facilitated the analysis of the report and the followed evaluation.

In order to investigate issues related to this thesis, literature was reviewed and experts were interviewed (see Figure 5). Apart from the final report, further literature on composting in developing countries, material flow analysis (MFA) and process cost accouting was reviewed.

In a further step, the use of Umberto 5.0 was studied. Background knowledge and funcionality of the new software was aquired. Feasibility and potential of use in this thesis was assessed. And the required type of data for implemenation was determined.

Furthermore, data of the case study was analysed and structured according to the software's requirements. The previously mentioned report suffers from some limitation. Some of the data presented is not consistent or does not fulfill the accuracy required. Therefore data could not be simply transferred.

In a next step, the system being of interest was defined. Therefore, system boundaries were determined. Furthermore, all processes for the current system and additional processes for all composting scenarios were defined.

Data was verified according to plausibility and completeness by expert judgements. Questionable data was replaced, whereas missing data was searched for and added. Preparation of data was mainly done with Microsoft EXCEL using the functionality of spread sheet analysis.

Then, the data was implemented. The current system, as well as the composting scenarios was modelled using the features of Umberto 5.0. Materials, transitions and their specifications, places, as well as parameters were defined. Financial data was implemented after determination of specific cost drivers for each process. System efficiency was considered as the same in all scenarios, thus scenarios were modelled based on the current system.

Once completely defined and implemented, the model was calculated. Results for each scenario were analysed and verified using the report of the case study and further literature. First of all, the current system was calculated and calibrated by changing specifications and parameters until the results were corresponding to the reports data. Secondly, the same procedure was used to calculate the results of the composting scenarios.

In order to analyse the systems performance and stability, a pragmatic sensitivity analysis was conducted determining the most important parameters. In addition the results of the current system and all composting scenarios were compared. Comparision and interpretation of the results lead to start the final reporting.

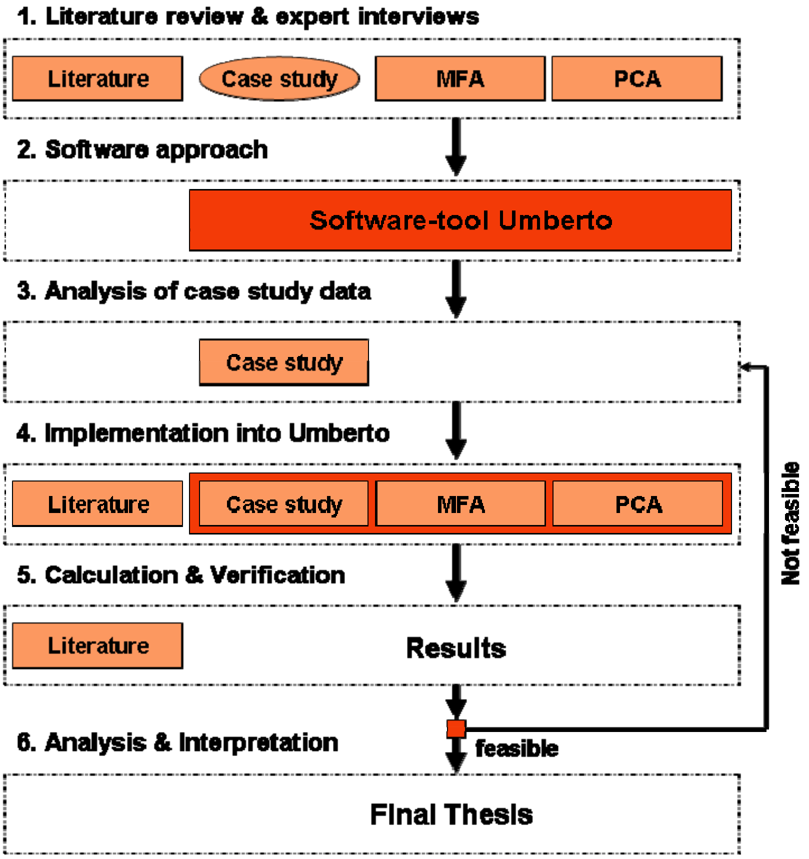

***Figure 5**: Schematic illustration of methodology used in this study. Starting from literature review to the point of final reporting, the coarse procedure is presented.*

3. Case Study in Asmara

3.1. Background Information

3.1.1. General Situation

Eritrea, located in the horn of Africa across the Red Sea, is one of the youngest african nations. It became independent in 1991. In the North and West Eritrea shares boundaries with Sudan, in the South with Ethiopia and in the Southeast it borders on Djibouti. The country is divided into six administrative regions. One of these regions is the Administration of Maakel Region (AMR), which includes the City of Asmara, the capital city of Eritrea, with a population of about 400'000 (official estimate 2003).

After getting independend Eritrea was aiming at a sustainable environmental management, which means available national resources have to be used carefully and to their full capacity by integrating all concepts of recycling and reuse. Thus, in 1995, the Governement of Eritrea prepared an Environmental Management Plan (EMP-E) (Gebremehdin 1998). This EMP-E keeps in view of the concept of sustainable development and the recommendation of Agenda 21 of Rio Summit in 1992[12]. The EMP-E is a blueprint for the protection of the scarce environmental resources considering different evironmental concerns (Srikanth 2003).

3.1.2. Environmental Concerns

Land Degradation & Use of Landfill Material

Agricultural productivity in Eritrea is low due to widespread land degradation. As a matter of fact, soil degradation results from soil erosion, deforestation, as well as overcultivation over a long period of time[13]. In addition, the shortage of rainfall causes droughts, thus crop production in Eritrea is low. Consequently, soils are often dry and very poor in organic matter and other plant nutrients like nitrogen and phosphorus (Dejene 2003).

Sustainable improvement of crop production can be achieved by regulated application of decomposed organic matter. In Eritrea, a part of potential organic feritliser is used for other purpose, such as for animal feed, fuel substitute or construction purposes (Drescher and Tesfay 2005).

However, in the last few years, farmers started to be aware of the potential of organic material from the municipal landfill. The application of landfill material causes an increase in organic matter to the soils. Hence, similar to compost, landfill material seems to have a huge potential regarding enhancment of crop production and thus serves as a key factor for food security, particularly in Asmara.

Despite benefits, the use of landfill material causes risks. Beside organic matter landfill material contains inorganic residues, such as plastics, metal scrap, glass pieces, bones ect. Apart from this, mined material contains invisible contaminants like heavy metals and persistent organic chemicals (Drescher and Tesfay 2005) whose impacts are not well studied. Both types of contamination could have severe effects on humans and animals, as well as on the surrounding environment.

Greenhouse Gas Emission & Leachate at Landfill Site

In general there is no tradition of separating solid waste in Asmara. Part of the organic waste is used as aminal feed, but in general organic waste is disposed togehter with the inorganic fraction on the municipality landfill.

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[12] Source: www.un.org

[13] Source: http://www.fao.org/docrep/meeting/x3976e.htm

As discussed in section 1.3.1 organic matter in disposal sites enhances different environmental risks, such as emission of greenhouse gases or groundwater pollution through landfill leachate.

Due to a lack of gas management Asmara's landfill is emitting a huge amount of greenhouse gases, especially methan and carbondioxide. Asmara's landfill is located in a valley-like depression, which leads to a small stream, thus surface water might be contaminated. However, leachate on Asmara's landfill should also not be ignored.

3.1.3. Potential Improvement with Composting

Solid waste management in Asmara is considered as a system with a high potential in reusing organic waste due to an organic waste content of about 65% (Habtetsion, Ghirmay et al. 1999). Compared to other african cities, Asmara has a well functioning collection system. Nevertheless, apart from environmental concerns, Asmara is facing problems with waste transportation capacity and landfill management. The reuse of organics in Asmara could reduce these problems considering the benefits of composting:

- Savings on transport cost
- Extension of landfill lifespan
- Generation of employment
- Reduction of greenhouse gas emissions
- Reduction of water pollution

Additionally a market for compost is likely to be established. Currently farmers already collect and pay for landfill material, which has a lower quality than compost. According to a study (Drescher and Tesfay 2005) done on landfillmaterial sale in Asmara, farmers are willing to pay more for materials having a better quality, thus the availability of a market for compost can be taken for granted.

3.2. Definition of System

The Administration of Maakel Region (AMR) has different departments and units. One of them, the Sanitation Unit (SU), is under the Department of Economic Development and has an overall responsibility for sanitation issues in Asmara and the surrounding villages. Sanitation issues involve the management of solid and liquid waste. In the following the system of interest is defined.

3.2.1. System Boundaries

In order to evaluate the economical impact of composting in Asmara, main activities which could be influenced by the implementation of composting were considered. Basically all SU activities related to the SWM could be affected by composting. Therefore the system boundaries could not be defined as a function of area or space. But they were defined according to the functionality or responsibility of the SU. The scope of responsibility of the SU was considered as the defined system to be assessed, excluding activities which are either not related to solid waste management or not performed on a regular basis. Activities not considered in this study were:

- liquid waste collection & latrine service
- dog hunting
- cleaning campaign days (only organised once in a year)

3.2.2. Definition of Processes

According to MFA terminology (see section 2.1.1) collection, transport and storage of waste can be defined as processes. Therefore, based on the composition of data given in the report (Kubrom, Mehari et al. 2004) SWM activities performed in Asmara were classified into six main processes. These processes are briefly presented in the following:

- **Administration:** Domain of the SU, which is responsible for the entire management of solid waste collection in Asmara.
- **Street sweeping:** A type of solid waste collection which includes cleaning of streets in the city and transport to transfer points.
- **Transfer point:** A designated point, often at the edge of a neighborhood, where small collection vehicles (such as wheelbarrows) transfer municipal waste into containers which are collected by larger vehicles for transport to a disposal site.

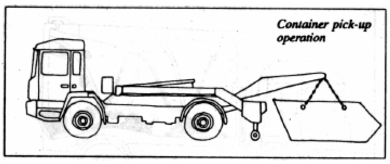

***Figure 6:** Skip loader with skip used for skip collection in Asmara. Source: (Attarwala 1993)*

- **Skip collection:** A type of solid waste collection using skip containers in order to transport waste. Skip containers (skips) are big and open containers which can be transported by skip loaders (Figure 6).

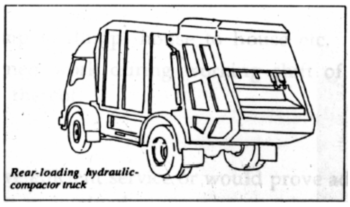

***Figure 7**: Compactor truck used for block collection in Asmara. Source: (Attarwala 1993)*

- **Block collection:** A type of solid waste collection where waste is collected directly from households or other places by vehicles and transported to the disposal site. A collection schedule is set, thus households are prepared for emptying their waste-bins into the collection vehicles slowly passing by. In Asmara mainly compactor trucks are used for block collection (Figure 7).
- **Disposal site:** The final placement of municipal solid waste that is not recycled.

3.2.3. Definition of Materials

According to MFA terminology materials have to be defined. In this study different types of waste flows are of main interest. Waste as a good which gets transported, processed, used and disposed is defined as the key material in this study. A detailed definition of waste types, as well as further materials relevant in this study is given in section 4.1.2.

3.3. Description of Baseline: The current System

In the following the system defined in the previous section will be described. It will be the basis for the following material flow and cost analysis.

3.3.1. General Characteristics

Generation, density and composition of solid waste are important characteristics of a SWM system. Therefore they are presented in the following.

Solid Waste Generation

According to various studies waste generation in Asmara decreased over the last decade. Based on a study (Habtetsion, Ghirmay et al. 1999) conducted in 1999, the waste generation was estimated to be 94’452 tons per year. The per capita generation was assumed to be 0.75kg per day.
According to a measuring campaign conducted in 1998/99 the generation was estimated to be 68’820 tons per year.
The current estimations (Kubrom, Mehari et al. 2004) are based on a measuring campaign carried out in 2004. The measurement results indicated a waste generation of 53’332 tons per year.
The decline in waste generation can be seen as a consequence of changing waste composition leading to a lower waste density. Nevertheless, these huge differences are mainly generated due to use of different density data.
Basically, all calculations done in previous studies are based on data officially given by the SU (Drescher 2003). The SU report provides data including the number of collection trips going to the municipal landfill.
Before 2004 waste densities and transport capacities were roughly estimated.
But in 2004, a measuring campaign was conducted using a weighing bridge of AMR. 265 waste collection vehicles were measured. The transport capacity was calculated out of that data.
The data used in this thesis is based on the measuring campaign in 2004. Considering a coverage of 80% (Habtetsion, Ghirmay et al. 1999) the amount of waste collected and transported by the SU is about 44’364 tons.

Composition of Solid Waste

Waste in Asmara origins from various sources, such as households, commercial places, institutions, street sweepings, construction and demolition debris, hospitals and medical centers, as well as industries. Different sources cause different types of waste. According to a study (Habtetsion, Ghirmay et al. 1999) done on the composition of Asmara’s solid waste, 70% of the waste originates from domestic origin and 14.2% from industries. Other sources generate significantly less waste as shown in Table 1.

***Table 1**: Asmara's solid waste types. Waste types and their origin are presetned according to fraction of total solid waste.*

Type of waste	Source	% Weight
Domestic	All households and small shops waste	70.0
Industrial	All factories, slaughterhouse, garages, workshops and handcrafts	14.2
Commercial and market	Market places, entertainment centres, hotels, restaurants, tea or coffee shops	4.4
Institutional	Government and NGO offices, International organisations, University and schools.	4.8
Medical	Hospitals, health centres, clinics and pharmacies	1.6
Others	Street sweepings, plant trimmings, left over construction waste	5.0
Total		100.0

Source: (Habtetsion, Ghirmay et al. 1999)

The same study assessed the composition of Asmara's solid waste as given in Table 2. Food waste with a content of 52.2 % is the dominant fraction in Asmara‘s waste. Considering paper and cardboard the organic waste fraction is stated to be around 65%.

***Table 2**: Asmara's solid waste composition.*

Component	Fraction %	Moisture Content %
Food waste (organic waste)	52.2	70
Paper and card board	12.9	5
Plastic and textile	6.3	6
Metal	2.2	3
Glass	2.0	2
Leather and Rubber	1.4	6
Ceramics and stone	0.9	8
Others (dust-ash)	22.4	8
Total	100.0	20

Source: (Habtetsion, Ghirmay et al. 1999)

Density of Solid Waste

Estimates of waste densities in Asmara are based on data collected during different weighing campaigns. Methodologies of these campaigns, as well as waste densities changed a lot within the last decades. According to the SU, the decline of waste density is caused by a change of consumption patterns. Especially a reduction of ash and the introduction of plasics in domestic waste lead to a lower density. Within this study density data from 2004 was considered as most reliable.

***Table 3**: Waste densities in Asmara in different periods of time.*

Vehicle/Skip	Density (kg/m3)		
	Before 1998	1998	2004
Big compactors	311	193	82
Medium compactors	335	299	131
Small Compactors	-	267	167
Average	323	253	127
FIAT 110	621	329	214
Mercedes	669	355	215
Average	645	332	215
Big Skip	857	500	357
Small Skip	870	440	320
Average	864	470	339

Source:(Kubrom, Mehari et al. 2004)

3.3.2. Description of Processes

The description of each process is divided into two parts. The first part describes labour and materials used for each process. In the second part financial data is presented.

Financial data considers investment and operation costs. Investment costs are considered as imputed costs, such as depreciation and interest on capital. The formula for depreciation and interest on capital used in this study are presented in section 2.1.2.

Goverments often define a standard period of time over which a particular type of asset should be depreciated. For vehicles and static equipment this period is often 5 years and 15 years, respectively (Coad). The salvage value is determined as 25% of the purchase value (Kubrom, Mehari et al. 2004). The salvage value is relatively high, compared to data in industrialised countries. This is due to the fact that vehicles in developing countries are used much longer than in industrialised nations. For the interest on capital common rates are between 6% and 9% (Steinfeldt, Petschow et al. 2002). In this study a rate of 6% was used.

If not indicated otherwise, all costs shown are annual costs. However, detailed tables for calculation of depreciation and interest on capital are presented in the Annex 9.1.

In the following the processes definded in section 3.2.2 will be described. The order of presentation is not done according importance, but it is related to the direction of solid waste flow in the system, which goes from collection to the final disposal. Administration as a process managing the entire system is described at the end.

Street Sweeping

The sweeping of streets is done manually by SU workers, mainly women (Habtetsion, Ghirmay et al. 1999), using brooms and wheelbarrows for collection and transport. In 2004, the number of street sweepers in Asmara was 407 as shown in Table 4. The type of waste collected from the streets generally includes paper, plastics, soil, vegetable waste (around market areas), dry palm tree leaves and sometimes dead animals. A survey showed that almost all workers dispose their collected waste into skip containers (see skip collection). The average distance from the place of sweeping to the skip is assumed to be around 1.5km. One single worker is able to make four trips to the skip each day, carrying waste with an average weight of 30kg per trip (Kubrom, Mehari et al. 2004).

***Table 4**: Total amount of waste collected by street sweeping. The amount of waste is based on the number of workers, the number of trips per day and the amount of waste per trip.*

Number of worker	Number of trips / worker / day	Amount of waste / trip	Amount of waste / worker / day	Amount of waste / year
		kg	t	t
407	4	30	49	17827

Street sweeping is labour-intensive and thus, process costs mainly depend on salaries, which are about 9’000 Nakfa (600$) per year as shown in Table 5.

In addition imputed cost and costs for brooms and water are considered. Water consumption for cleaning purposes is estimated to be about ten litres per worker and day. According to Kubrom et al. 1m^3 of water is charged around 7.5 Nakfa.

The process of street sweeping does not generate any income, therefore a deficit is resulting.

***Table 5**: Total costs for the process of street sweeping. Total costs include investment costs, such as depreciation and interest on capital, and operation costs.*

Investment costs	**Quantity**	**Unit**	**Price / Unit**	**Amount**	**Unit**
Depreciation wheelbarrow	407	-	500	30'525	Nkf
Interest on capital wheelbarrow	407	-	500	7'631	Nkf
Total investment costs				38'156	Nkf
Operating costs					
Brooms	2'490	-	12	29'880	Nkf
Water	1'486	m3	7.5	11'145	Nkf
Worker salary	407	-	9'000	3'663'000	Nkf
Total operating costs				3'704'025	Nkf
Total costs				**3'742'181**	Nkf
Total income				0	Nkf
Deficit				-3'742'181	Nkf

Transfer Point

The transfer point represents all skip containers (skip container, see Figure 6), which are distributed all over Asmara. They serve as near temporary waste storage sites for households, institutions, as well as for street sweepers.

The number of skips is increasing due to population growth and expansion of the city. In 2004 the number of skip container increased to 268 (Kubrom et al.). Transport capacity depends on the skip size. Therefore skips are categorised into two types; big and small, with a loading capacity of about 2.5 tons and 1.6 tons, respectively, as shown in Table 6. The number of trips is recorded by the SU, thus waste haulage can be estimated.

***Table 6**: Number of trips and amount of waste collected by skip collection in 2003. Size of skip containers is categorised into small, medium and big.*

Vehicle type	Average weight per truck	Measurement description	Average per month	Total per year
Big	2.3 t	No. of trips	110	1320
		Weight (t)	253	3036
Medium	1.7 t	No. of trips	418	5016
		Weight (t)	710	8532
Small	1 t	No. of trips	230	2760
		Weight (t)	228	2760
Total	-	No. of trips	756	8316
		Weight (t)	1191	14292

Source: (Kubrom, Mehari et al. 2004)

Major criterium for placement of skips is the population size within a certain area. Basically, the more people are living in a certain area the more skips are required. The collection frequency of skips depends on the amount of waste disposed of into the skip. Filled skips are reported to the SU by workers or locals, collected and replaced by an empty skip. Most of the skips get collected once a week or daily. But few get replaced on a monthly basis. However, a fixed collection schedule does not exist.

Costs for this process only include depreciation and interest on capital of skips. Labour and other materials are not required as shown in Table 7.

***Table 7**: Total costs of the process of transfer point. This process only includes investment costs for skip containers.*

Investment costs	Quantity	Unit	Price / Unit	Amount	Unit
Depreciation skips	268	-	*	308'200	Nkf
Interest on capital skips	268	-	*	231'150	Nkf
Total investment costs				539'350	Nkf
Total costs				**539'350**	Nkf
Total income				0	Nkf
Deficit				-539'350	Nkf

Skip Collection

Skip collection is used in areas, where block collection is absent, for example due to difficult access (narrow roads etc.). Instead of using a mechanical transport, locals bring their waste to the skip container.

In 2003 five out of six municipal skip loaders were operating. The number of trips per day done by a skip loader depends on the day of collection. On average a skip loader is able to make seven trips per day. One trip involves collection, transport and emptying of a skip, as well as replacement of a following skip. One skip loader requires in average one driver and two assistants.

Skip collection is characterised by high investment costs, such as imputed costs for skip loaders. Considering operational costs the major part of costs is due to fuel and lubricant consumption as shown in Table 8.

Table 8: *Total costs for the process of skip collection. The total costs include investment costs, such as depreciation and interest on capital, and operational costs.*

Investment costs	Quantity	Unit	Price / Unit	Amount	Unit
Depreciation skip loader	6	-	*	1'685'310	Nkf
Interest on capital skip loader	6	-	*	421'328	Nkf
Total investment costs				2'106'638	Nkf
Operating costs					Nkf
Fuel & lubricants (+30%)	60	m3	7'700	462'000	Nkf
Water	44	m3	7.5	330	Nkf
Driver salary	6	-	15'000	90'000	Nkf
Driver incentives	6	-	3'000	18'000	Nkf
Assistants salary	12	-	9'000	108'000	Nkf
Assistants incentives	12	-	1'500	18'000	Nkf
Car wash	6	-	1'000	6'000	Nkf
Maintenance	6	-	14'000	84'000	Nkf
Insurance	6	-	1'200	7'200	Nkf
Total operating costs				793'530	Nkf
Total costs				**2'900'168**	Nkf
Total income				0	Nkf
Deficit				-2'900'168	Nkf

Block Collection

In 2004, the number of operating block collection vehicles was eleven (Kubrom, Mehari et al. 2004). Six of them were compactor trucks and five old common trucks. Four old trucks were under maintenace, thus they were not considered for waste collection. Block collection trucks are categorised into three different types; big, medium and small having an average load of 2.3 tons, 1.7 tons and 1 tons, respectively. The number of trips to the landfill is recorded by the SU, thus waste haulage can be estimated.

Table 9*: Number of trips and amount of waste collected by block collection in 2003.*

Skip size	Average weight per skip	Measurement description	Average per month	Total per year
Big	2.5 t	No. of trips	962	11'544
		Weight (t)	2'405	28'860
Small	1.6 t	No. of trips	61	122
		Weight (t)	98	1'176
Total	-	No. of trips	1'023	11'666
		Weight (t)	2'503	30'036

Source: (Kubrom, Mehari et al. 2004).

As for the skip collection, expenses for fuel and lubricants are high. Furthermore, block collection is a process which requires cost-intensive vehicles for operation. As mentioned before, eleven block collection vehicles were operating. Taking the other four vehicles being maintained in regard, in total 15 trucks are considered for the cost analysis.
The crew of each vehicle consits of a driver and two or three assisstants, who help dwellers emptying their waste-bins.

***Table 10**: Total costs for the process of block collection. The total costs include investment costs, such as depreciation and interest on capital, and operational costs.*

Investment costs	**Quantity**	**Unit**	**Price / Unit**	**Amount**	**Unit**
Depreciation collector truck	15	-	*	679'781	Nkf
Interest on capital collector truck	15	-	*	175'859	Nkf
Total investment costs				855'640	Nkf
Operating costs					Nkf
Fuel & lubricants (+30%)	80	m3	7'700	616'000	Nkf
Water	110	m3	7.5	825	Nkf
Driver salary	15	-	15'000	225'000	Nkf
Driver incentives	15	-	3'000	45'000	Nkf
Assistants salary	30	-	9'000	270'000	Nkf
Assistants incentives	30	-	1'500	45'000	Nkf
Car wash	15	-	1'000	15'000	Nkf
Maintenance	15	-	14'000	210'000	Nkf
Insurance	15	-	1'200	18'000	Nkf
Total operating costs				1'444'825	Nkf
Total costs				**2'300'465**	Nkf
Total income				0	Nkf
Deficit				-2'300'465	Nkf

Disposal

Solid waste collected by the SU is mainly disposed of at the municipal landfill located around 6 km out of Asmara. Only construction waste goes to another place specially prepared for debris.

According to United Nations Environmental Programme[14], Asmara landfill is classified as open dump as it is poorly sited with unknown capacity, having no cell planning and no site preparation. In addition, leachate and gas management activities are missing. Therefore, uncontrolled fire is often a problem.

Waste disposal started about 60 years ago, but data recording did not start until 1998. Thus, data on landfill volume is not available. In 1996, the volume and density of the landfill was estimated to be about 518'000m^3 with a waste density of 0.85 tons per m^3 (Habtetsion, Ghirmay et al. 1999).

Nowadays, the existing activities on the landfill include recording of waste disposal trips, disposal of waste to assigned places, spreading of waste by a front loader, covering the landfill with soil, as well as recording of the amount of landfill material sold.

Since 1998 landfill material is sold to farmers as a soil conditioner and fertiliser. Despite environmental concerns (see section 3.1.2) the demand for landfill material increased within the last few years. In the report from Drescher (Drescher and Tesfay 2005) it is indicated that 48 villages around Asmara are costumers of the landfill material. The proximity of the market for landfill material ranges from 4 to 60km from the landfill site. In Figure 8 yearly landfill material sales are summarised.

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[14] Source: www.unep.org

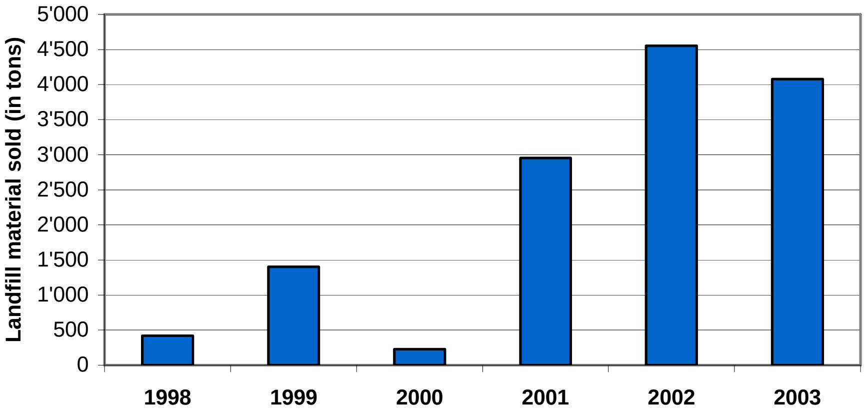

***Figure 8**: Amount of landfill material sold in the last few years. Source: (Drescher and Tesfay 2005).*

At the landfill only one front loader is used being operated by one out of the three workers at the landfill. Other infrastructure does not exist and thus investment and operational costs are relatively low compared to other processes.

Landfill management is the only process, which directly generates income. Locals, mainly farmers, are charged for the landfill material they take to their fields. The SU charges 12 Nakfa per m^3 of landfill material. But a few farmers also pay for transport of landfill material to their fields. Apart from landfill material sale, locals pay for dumping and burning of waste that is brought individually.

***Table 11**: Total costs for the process of landfill. The total costs include investment costs, such as depreciation and interest on capital, and operational costs. Apart from costs, incomes are acounted.*

Investment costs	**Quantity**	**Unit**	**Price / Unit**	**Amount**	**Unit**
Depreciation loader	1	-	*	193'170	Nkf
Interest on capital loader	1	-	*	48'293	Nkf
Total investment costs				241'463	Nkf
Operating costs					
Fuel & lubricants (+30%)	18	m3	7'700	138'600	Nkf
Water	11	m3	7.5	83	Nkf
Staff salary	3	-	10'000	30'000	Nkf
Maintenance	1	-	14'000	14'000	Nkf
Insurance	1	-	1'200	1'200	Nkf
Total operating costs				183'883	Nkf
Total costs				**425'345**	Nkf
Income					
Landfill material sale	5000	m3	12	60000	Nkf
Transport of landfill material				4500	Nkf
Dumping of waste	-	-	-	1'000	Nkf
Burning of waste	-	-	-	9'000	Nkf
Dead animal picking & Dumping	-	-	-	250	Nkf
Total income				74'750	Nkf
Deficit				-350'595	Nkf

Administration

The administration is located in the SU headquarter, which is place of employment for nine persons.
The SU head quarter was constructed around 1935. Based on market prices of material and labour in 2003, the building is valued of approximately 1’785’000 Nakfa. Regarding the age of the building, it is assumed that the building is already amortised. Thus, deprecition costs are not considered in the calculation of annual costs.
In the following Table 12, costs for management, as well as revenues are illustrated. Revenues only consit of waste service fees. Service fees are payed by households and institutions for receiving service from the municipality, such as waste collection and disposal by the SU. The amount of service fees depends only on location and size of a certain property. Hence, it is not a function of particular collection processes. Service fees being the main income for the SU, not only include solid waste collection, but also liquid waste collection.

***Table 12**: Total costs for the process of administration. The total costs only include operational costs. Service fees are accounted to this process resulting in benefits.*

Investment costs	Quantity	Unit	Price / Unit	Amount	Unit
Total investment costs				0	Nkf
Operating costs					
Head of the Unit	1	-	17'000	17'000	Nkf
Cleaning Head	1	-	12'000	12'000	Nkf
Cashier	1	-	10'000	10'000	Nkf
Typist	1	-	10'000	10'000	Nkf
Accountant	1	-	11'000	11'000	Nkf
Purchaser	1	-	11'000	11'000	Nkf
SU guards	3	-	8'400	25'200	Nkf
Water	33	m3	7.5	248	Nkf
Stationery	-	-	-	9'000	Nkf
Detergent	-	-	-	13'000	Nkf
Electricity	-	-	-	1'400	Nkf
Communication	-	-	-	1'500	Nkf
Total operating costs				121'348	Nkf
Total costs				**121'348**	Nkf
Income					
Waste service fee	-	-	-	12'282'145	Nkf
Total income				12'282'145	Nkf
Benefit				12'160'798	Nkf

3.4. Description of Scenario: Centralised Composting System

3.4.1. General Assumptions

Introducing a centralised composting system does not imply replacement of the entire facilities of the current system. In contrast, practically all the facilities and labour from the existing system are utilised.
Implementation of a centralised composting plant leads to a system where waste from multiple sources is transferred to one composting plant.

3.4.2. Centralised Composting System

In this scenario the centralised composting plant is assumed to be built on Asmara’s municipal landfill site. All waste collected by the SU is going to the composting plant. At the plant the mixed waste gets separated. The separated waste not being useful for composting is disposed of at the municipal landfill closeby. As a consequence of this, the collection and transport to the landfill remains the same and does not require any reorganization.

3.4.3. Centralised Composting Plant

Characteristics of the Plant

The total amount of mixed waste collected in Asmara by the SU during the year 2003 is estimated to be about 44'364 tons. Based on this amount of waste the capacity of the plant is expected to be 180 tons of mixed waste per day. This considers a downtime of 122 days per year based on the fact that there are only 243 working days in Eritrea.

Based on data from existing centralised composting plants in developing countries the land requirement is estimated. It is assumed that the area required for a plant of this size is about 20'000m^2. Water demand is expected to be about 13 tons per day based on data from an existing plant in India (Sandec 2002). Further characteristics in Table 13 are summarised from Table 14. According to an experts[15] advice two main guidelines regarding cost assumptions of a plant are considered:

- The fixed costs per ton of mixed waste for a centralised composting plant vary between 6'500$ up to 9'000$.
- One worker is handling at most 2 tons of waste per day.

In this study the fixed costs per ton are assumed to be around 5'800$. The fixed costs are expected to be lower due to the several cost savings. The cost savings are mainly due to already existing facilities at the landfill.

The second guideline gives the ratio between the number of worker and the capacity of the plant. In this scenario 105 workers process 180 tons of mixed waste per day. Hence, the number of workers should be able to process the incoming waste.

Table 13*: Plant characteristics; the centralised plant is dimesioned for a capacity of 180 tons of incoming mixed waste per day.*

Location	**Asmara, Eritrea**	
Technique	**Windrow Composting**	
Feed stock	**mixed waste**	
Plant characteristics	Unit	Quantity
Area (ha)	m2	20000
Capacity	t/day	180
Waste density	kg/m3	210-350
Organic waste	%	50
Water demand	t/day	13
Costs for power supply	$/month	110
Fix workers	-	105
Investments / fixed costs	$	1'037'000
Total operational costs	$/year	184'333
Fixed cost / ton mixed waste	$/t	5'761
Workers / ton mixed waste	/t	0.58

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[15] Mr. Enayetulla, enineer experienced in construction of centralised composting plants (wastecon@agni.com).

Process Description

The collection vehicles are weighted on the weighing bridge. After that, they discharge the loaded waste in the reception area (A, in Figure 9). From there the waste is transferred by a front loader into the feed hopper with an incorporated steel slat conveyor. In the pre-sorting station, cardboard and office waste paper, glass, plastic, textiles and bones are separated by hand and thrown into the respective boxes where recovered materials are kept (B). The ferrous metals are removed to a large extent by an overhand magnetic separator. The selected subproducts are likewise baled by the presses. The materials free from ferrous metals drop into the mixing and screening drum where its moisture content is optimised by adding water. At the same time a general homogenisation of all products is then separated into two fractions - namely fresh compost to the fermentation park and unsuitable material for composting as rejects (C). The screen product is then automatically delivered via an inclined belt conveyor to the fermentation park where the product stacks up to a primary windrow. Here a windrow[16] turning machine takes over, moving the windrows periodically and gradually away from the centre of the building towards its periphery. The coarse compost (D) from the outermost windrow can be either sold directly for land reclamation projects and general agriculture or it can be refined by the fine treatment line (E) (Bühler 1986).

Legend for Figure 9:

1) Weighing bridge
2) Steel slat conveyor
3) Belt conveyor
4) Hand picking station
5) Presses
6) Magnetic separator
7) Mixing drum
8) Belt conveyor
9) Hangar belt conveyor with tripper
10) Windrow turning machine
11) Box feeder with chain conveyor
12) Sieving drum

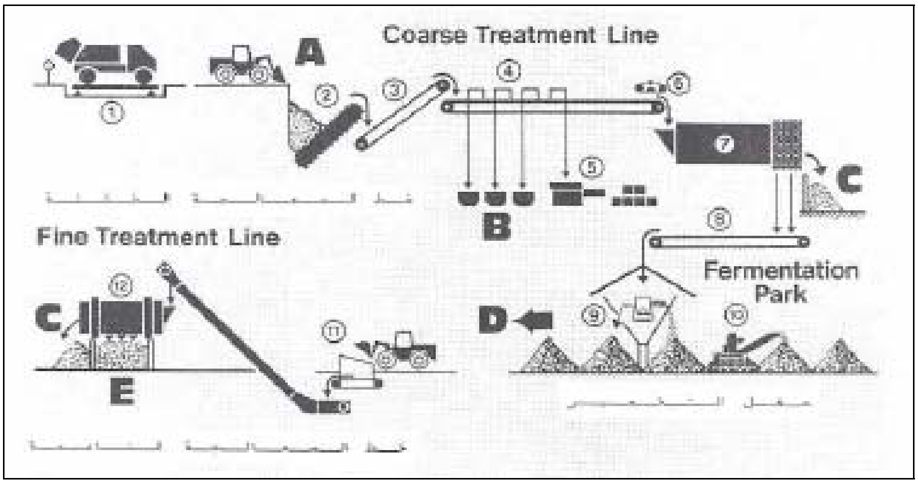

Figure 9: Schematic description of processing solid waste at a centralised composting plant. Source: (Bühler 1986).

Investment and Operational Costs

Being located on the landfill site induces a few logistical advantages resulting in cost savings. The rejected waste coming out of the separation process can be disposed of closeby. Hence, costs for transport can be saved. Furthermore, the use of the existing front loader from Asmara’s landfill is enabled and thus, an additional loader is not required. Additionally, the area for construction is already available as the landfill is already municipal property. Due to landfilling operations, the area is already leveled. Based on that, costs for land purchase and site preparation are expected to be comparativley low.

Additional saving can be expected due to the option of using the already existing municipal weighing bridge for measurments of collection vehicles. A new weighing bridge is therefore not required.

Salaries for workers are based on the SU report (2003). The salaries for workers are expected to be around 9’000 Nakfa per year (about 600$ per year) which corresponds to salaries of street sweepers in Asmara. Salaries for manager, technical officer ect. are correspondingly higher. These salaries might be considered as low. But based on other studies salaries of plant

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[16] Windrow composting is a system of composting, where compostable waste is piled in a long row to decompose (windrows)

workers seem seem to be in that range. According to a study in Nepal (Bushan and Anish 1997) composting plant workers earn about 430$ per year. Supervisors salaries are stated to be around 670$ per year.
Investment and operational costs are assumed as follows. Listed plant facilities refer to the Figure 9.

Table 14*: Cost assumptions for a centralised composting plant having a capacity of 180 tons of incoming mixed waste.*

Assumptions for costs	**180 t / day mixed waste**		
Investment costs	Unit	Quantity	$
Land acquisiation			not required
Site development	4$/m2	20000 m2	80'000
Machinery	additional truck	1	190'000
	front loader	0	available
	weight bridge	0	available
	steel slat conveyor	1	10'000
	belt conveyor	2	4'000
	hand picking station	2	20'000
	presses	1	10'000
	magnetic separator	2	80'000
	mixing/screening	1	180'000
	hangar belt conveyor with tripper	1	30'000
	windrow turning machine	2	400'000
	box feeder with chain conveyor	1	10'000
	rotating sieving drum	1	23'000
Total			1'037'000
Operational costs		Quantity	$ / year
Labour, Salaries	Administration		available
	Manager	2	3'000
	Technical officer	4	5'000
	Technician	8	8'000
	Electrician	6	6'000
	Worker	75	45'000
	Vehicle driver	4	4'000
	Guard	6	3'600
	Total	105	74'600
Supplies & tools			1'000
Fuel & lubricants			25'000
Power supply	110 $ / month		1'320
Water	0.5 $ / m3	5000 m3 / year	2'500
Maintenance and repairs			3'400
Marketing			1'000
Training of labour			5'000
Interest on capital	windrow turning machine (6 %)	400'000	15'000
	static equipment (6 %)	367'000	13'763
Depreciation	windrow turning machine (5 year)	400'000	20'000
	static equipment (15 year)	367'000	18'350
Others			3'400
Total			184'333

Source: Summarised from (Fricke & Turk GmbH), (Kubrom, Mehari et al. 2004),(Sandec 2002) and expert judgment (Mr. Enayetulla).

Revenues from compost sale

Unlike the current system, compost will be produced and sold to farmers. According to Drescher (Drescher and Tesfay 2005) farmers are willing to pay more if the landfill material is sieved. In 2003 farmers payed 60 Nakfa for 5m^3 of landfill material. Taking the impurities, which make up 60% of landfill material, into consideration, farmers payed 60 Nakfa for 2m^3 of sieved material.

This implies that farmers would have paid more than 60 Nakfa for 5m^3 of landfill material free of unwanted scrap. It is not assumed that they would pay 150 Nakfa taking a linear increase of price into consideration. Nevertheless, it is expected that compost having a better quality than sieved landfill material can be sold at least to the same price. In this study it is assumed that all compost produced is sold at 20 Nakfa per m^3.

3.5. Description of Scenarios: Decentralised Composting Systems 1 & 2

3.5.1. General Assumptions

Decentralised composting refers to composting at community level, thus the sites usually process less than five tons of mixed waste per day. In this study the size of the decentralised plants is assumed to be three tons of mixed waste per day. This considers the downtime of the plants during holiday. The number of working days is set to be 243.

The total amount of mixed waste collected in Asmara by the SU during the year 2003 is estimated to be about 44’364 tons. Around 40% of the total collected solid waste is coming from street sweepings. Street sweepings are not recommended for use in the composting process due to the potential heavy metal content in the street dust. But the separation of street sweepings and household waste can not be done without a few changes in the current SWM. However, the implementation of decentralised composting implies modifications in the collection system. But the aim of this study is to present decentralised systems which are feasible to be implemented in the current SWM system. Based on this aim, two different scenarios for decentralised composting systems were evaluated. One considers the option of mixing household waste with street sweeping as it practised today. The other scenario considers a separate collection for street sweepings. The two scenarios are presented in the following sections.

3.5.2. Decentralised Composting System 1

The introduction of decentralised composting in Asmara implies more changes in the solid waste management than centralised composting. Due to the much lower capacity of decentralised plants a lot of small plants are required in order to process the generated waste in Asmara.

In this scenario some of the existing transfer points are considered as appropriate locations for decentralised plants due to several reasons. The transfer points already serve as collection points where waste is brought by street sweepers and locals.

Furthermore, skip containers are often located at open places where space for decentralised plants is expected to be available. Transfer points are spread all over Asmara. Hence, distances for waste collection are decreasing significantly. The transfer points not transformed into composting sites keep their function as temporary strorage sites and need no further replacement. Filled skip containers are collected by skip loaders and disposed of at the nearest composting plant. At the composting sites skip containers get filled with inorganic waste from separation process and further residuals from the composting process. They are then transported to the municipal landfill. The organic fraction is processed to compost that is sold to farmers.

As already experienced from landfill material sale farmers are willing to collect the fertiliser or pay for additional transport to their fields.

According to these assumptions implementation of decentralised composting does not imply a lot of changes in the principle of skip collection as waste is still collected in Asmara and transported to the landfill. In contrast, the principle of block collection changes significantly as waste is collected and disposed at the nearest composting plant. The transportation of waste to the municipal landfill is therefore omitted.

3.5.3. Decentralised Composting System 2

The second decentralised scenario is maily based on assumptions from the the first scenario. In the first scenario street sweepings get mixed with other solid waste. Therefore, the street sweepings have to be separated at the composting plant. Separation of street sweepings is, however, hardly to be done as there is only a coarse manual separation not covering the fine street dust.

In this scenario street dust is never mixed with other solid waste as there are separate skip containers available only for street waste. The additional skips only have an impact on the skip collection system. Block collection stays the same system as described in the first scenario.

Basically, skip collection is devided into two parts. One part of the vehicle fleet is responsible for collection of containers at the composting plant and for transportion to the landfill. The other part of the fleet is collecting skips containing houshold waste. These containers are emptied at the nearest composting plant and brought back.

3.5.4. Decentralised Composting Plant

Characteristics of the Plant

Based on data from a decentralised composting plant in Bangladesh (Rytz 2001), characteristics and costs were summarised and adopted to local conditions in Asmara. Space requirements are assumed to be about 0.3 ha for each plant.

Water consumption is about 0.3 tons per day, which corresponds to the demand per unit of waste for a centralised plant. This is not surprising as water demand mainly depends on biological processes and climate conditions which are more or less the same for both composting options.

Differences occur in costs for power supply. For a decentralised plant the costs are only about 100$ per year, whereas the same amount is spent on a monthly basis in a centralised plant. Low electricity costs are mainly due to the low-technology, labour-intensive working processes.

For a decentralised plant, investment costs per ton and number of worker per ton are in the same range as for a centralised plant. In this scenario the fixed costs per ton of mixed waste are planned to be about 7’809$. The number of workers is assumed to be six. Additionally, the work of one plant manager is taken into account.

Table 15*: Plant characteristics; the decentralised plant is dimesioned for a capacity of 3 tons of incoming mixed waste per day.*

Location	**Asmara, Eritrea**	
Technique	**Windrow Composting**	
Feed stock	**mixed waste**	
Plant characteristics	Unit	Quantity
Area (ha)	m2	3000
Capacity	t/day	3
Waste density	kg/m3	210-350
Organic waste	%	50
Water demand	t/day	0.3
Costs for power supply	$/year	102
Fix workers	-	7
Investments / fixed costs	$	23'428
Total operational costs	$/year	1'672
Fixed cost / ton mixed waste	$/t	7'809
Workers / ton mixed waste	/t	2

Process Description

The collected waste is manually separated and sorted into fractions such as easily degradable material, other recyclable materials and rejects (mainly inorganic). The recyclables are either sold or used by the plant-worker. The rejects are disposed of into a skip and transported to the landfill.

After separation the organic waste is piled up around an aerator[17]. The piles are covered by a shed, which protects the organic matter as well as the workers from rain and direct sunlight.

Furthermore, the piles are turned and watered periodically in order to optimise degradation of organic matter. Additionally the temperature is monitored. Decomposition efficiency strongly depends on temperature due to biological processes, thus the temperature control is of high importance. But also the control of the moisture content is not negligible as bacteria prefer contents of 40 to 60% without limiting aeration.

The decomposition process requires about 40 days depending on climatic conditions. In order to ensure mature compost that is safe to use, another two weeks of maturing[18] are needed.

Finally, the mature compost is screened in order to produce fine compost, free of rejects which have not been separated in previous steps. Additional rejects are disposed of, whereas the compost is applied for agricultural purposes around Asmara.

Investment and Operational Costs

The investment in equipment and other fixed assets is planned to be very limited, in order to maximise employment opportunities. Nevertheless, the composting process takes several weeks to complete, so that a substancial sum has to be invested in the work-in-process.

Investment costs basically depend on the costs for land aquisation. In this scenario it is assumed to be necessary. As the area next ot the transfer points is municipal property and free for use, the costs for land acquisation are neglegted. Apart from this, investment costs mainly depend on the processing area that has to be covered. These costs can vary from place to place within Asmara and thus are difficult to determine. But in this study the investment costs are defined to be around 23’500$ for each plant.

As shown in Table 16 the main part of operational costs is due to labour saleries. Salaries for workers can vary. But in this study, they are expected to be in the same range as for workers handling waste at the centralised plant (600$ per year). Other costs, such as for tools and supplies, are very low compared to centralised plants due to the manual waste processing.

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[17] Aerator: a construction often made out of wood which enables aeration of a composting pile in order to have aerobic condition within the waste pile.

[18] Maturing in composting process means the final decomposition of compost. The process does not require turning and watering of piles.

***Table 16**: Cost assumptions for a centralised composting plant having a capacity of 3 tons of incoming mixed waste.*

Cost assumptions	**3 t / day mixed waste**		
Investment costs	Unit	Quantity	$
Land acquisisation	5 $ / m2	3000	15'000
Construction of:			
Roofed sorting platform	2.4 $ / m2	360	864
Roofed composting shed	2.4 $ / m2	2140	5'136
Office, bath room, toilet and storage place	10 $ / m2	120	1'200
Roofed screening area	2.4 $ / m2	95	228
Water & electricity connection		-	1'000
Total			23'428
Operational costs		Quantity	$ / year
Salaries	worker	6	3'600
	plant manager	1	900
Supplies & tools			1'000
Power supply	8.5 $ / month		102
Water	0.5 $ / m3	100 m3	50
Maintenancefor equipment			200
Marketing			20
Others			300
Total			6'172

Source: Summarised from (Rytz 2001) with regard to local conditions.

Revenues from compost sale

The compost sold to farmers is considered to be of the same quality as the compost processed in centralised plants and thus, the price for sale is also set to be 20 Nakfa per m^3. All compost produced is assumed to be sold due to the existence of a market for landfill material.

But data on markets for recycables is not available and thus the value of these materials is not considered in this study.

4. Model of SWM

4.1. Development of Model

4.1.1. Importance of Modeling

By analysing complex relations in any system, most humans soon reach the limits of their faculties. Interdependences in dynamic processes within a large system are hard to grasp.

Nowadays it becomes more and more important to understand the functionality of such systems.

One possible approach to rendering such systems is to conceive appropriate models. All characteristics of the system that are relevant in a given context are to be transferred into a model. Thus the complexity of the system will be simplified before being represented in the model.

The degree of simplification of the system has to be chosen regarding to the desirable expressiveness of the model. Models have to be refined iteratively to reach the desired level of accuracy[19]. In this study the abstraction is done by definition of system boundaries, processes and materials.

4.1.2. Model Definition

The model is developed using the software-tool Umberto 5.0. The systems already descriped in previous sections are transferred into the software environment. Nevertheless, a detailed description of the model's structure is important as it leads to better traceability of calculations. One of the four material flow networks is presented in Figure 10. The development of the network in Umberto requires the definition of various elements. In the following these elements are described.

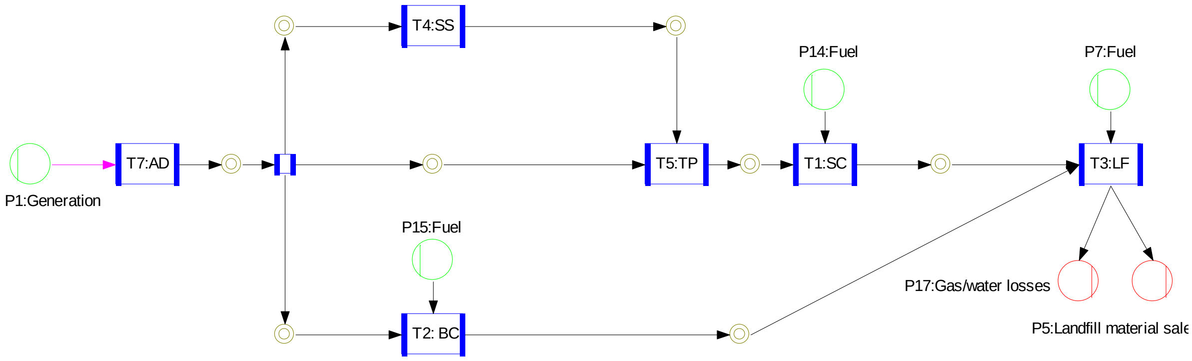

***Figure 10**: Systematic description of the SWM in Asmara (baseline) within the software tool Umberto 5.0 based on in- and output places, transitions and arrows representing the material flows.Transitions illustrated in this figure for the baseline are administration (AD), street sweeping (SS), tranfer point (TP), skip collection (SC), block collection (BC) and finally the landfill (LF).*

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[19] Source: www.umberto.de

Materials

In this study kilogramm is taken as the base unit for all materials, whereas names and descriptions of materials are presented as follows:

- **Mixed waste, compostable waste and rejected waste** are types of solid wastes as defined in 1. Obviously, mixed waste is a mixture of organics and inorganics. Due to lack of segregation maily all waste collected in Asmara is of mixed nature. According to the Environmental Protection Acency of the United States[20] mixed waste also contains hazardous and radioactive waste. This is hardly to be evaluated as detailed waste analysis is missing. However, the waste collected by the SU is defined as mixed waste in this study. Furthermore, compostable waste is defined as waste which is organic, untoxic and appropriate for composting processes, such as food waste, paper and cardboard. In addition, rejected waste as a term only used in this study is not officially recognised. But in the framework of this study it seems to be a valuable name due to the inclusion of all waste which is not relevant for composting. Specifically, rejected waste mainly consists of inorganic waste, but also organic waste coming from street sweeping activities, such as dust that is often contaminated with heavy metals.

- **Fuel & lubricants** stands for diesel fuel, as well as for lubricants used for operation of SU vehicles. An increase in fuel consumption is accompanied by an increase in consumption of lubricants. According to Tedros et al. (2003) the lubricants consumption is about 30% of the fuel consumption. This relation is questionalble as lubricant costs are expected to be lower than 30% of fuel costs. Nevertheless, this relationship is used to calculate the total expenses for fuel consumption as it corresponds to the data given in the SU report. Additionally, the price for diesel and lubricants is set to 8 Nakfa per litre, which corresponds to the market price in 2003. In order to determine the mass flow, the density is defined as 0.84 kg per litre[21].

- **Landfill material** contains decomposed organic matter, but also visible and unvisible contaminants, such as scrap materials and heavy metals, respectively. The material is currently sold to 12 Nakfa per m^3.

- **Compost** as such, is defined in section 1.3. Due to better quality the material is assumed to be sold at higher prices than landfill material. The price per m^3 of compost is estimated to be 20 Nakfa.

- **Water** is required during the composting process in order to keep optimal humidity conditions for bacteria. Water used for cleaning purposes is not considered in the mass balance, but is also included in the cost calculations. Based on the previous study (Kubrom, Mehari et al. 2004) the price for water is set to be 7.5 Nakfa per m^3.

- **Gas & water losses** occur during the degradation of organic matter. Gas emissions and waste water quality depend on the nature of treatment processes and thus change within the three different scenarios. Different kinds of emissions result in different impacts on the environment. Nevertheless, only the coarse dimensions of mass flows are taken into account without considering gas or water composition.

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[20] Source: www.epa.gov

[21] Source: http://bioenergy.ornl.gov

Input Places

The system boundaries involve the in- and output places, where materials are entering or leaving the system. As shown in Figure 10 the in- and output places for the current system are represented as green and red circles, respectively. Each place represents the decline or accumulation of materials within the period of a year.

- **Generation** represents the solid waste generated in Asmara and surrounding villages which is covered by the SU as described in section 3.2.1.

- **Fuel & lubricants** represent the fuel and lubricant consumption of respective processes. It is related to the number of vehicles and the driving distance of vehicles. Despite of being dependent on vehicles type as well as haulage, these factors are not considered due to lack of data. In 2003 a small-scale investigation was carried out on fuel consumption of compactor trucks and skip loaders in Asmara. Two vehicles[22] of each type were analysed and readings from odometer and fuel consumptions were recorded during waste collection, transport and disposal. Average values for fuel consumption for both vehicles were similar. The average value of 0.32 liter fuel per km was therefore taken for both vehicles types. Based on other studies the value seems to be reliable. In one study (Chandler, Norton et al. 2001) avarage values of 0.33 liter diesel per km for waste transport vehicles and 0.8 liter diesel per km for waste collection vehicles are given. Another specific value for fuel consumption of a diesel truck is 0.328 liter per km (McDougall, White et al. 2000). The fuel consumption of the front loader was assumed to be 12 liter per hour as it is not mainly depending on transport distances, but on operation time[23].

Output Places

- **Landfill storage** includes the amount of waste that is disposed of at the municipal landfill.

- **Gas & water losses** represent the amount of gas emissions and leachate water that occurs during the degradation of organic matter within the landfill. Type and quality of gas emissions and water are not defined or quantified. Only the total mass loss is taken into account in this quantitative analysis.

- **Landfill material sale** stands for the amount of landfill material that is sold to local farmers in 2003. The prices for landfill material is known and therefore involved in the cost calculations of this study.

- **Compost** represents the amount of compost produced.

Cost Plan

A cost plan is required in order to allocate various costs. Costs from different processes are summarised within the cost plan according to defined cost types. Within Umberto the cost plan is defined on a project level and is thus, valid for the baseline and all scenarios. In the following Table 17, cost types, as well as the species of costs are illustrated.

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[22] Only two odometers were operating. Therefore additional trucks could not be analysed.

[23] Source: http://www.hand.ch/d/produkte/tunnelbagger/findex.html

***Table 17**: Allocation of cost species to the defined cost plan according to cost types.*

Cost types	Content
Income	
Income from products	lanfill material sale, compost sale
Income from services	service fee, dumping & burning of waste, animal picking & dumping
Operation Expenses	
Expenses material	
Expenses raw material	water
Expanses auxiliary materials	fuel, lubricants, brooms, stationery, detergent
Expenses for service	
Expenses external service received	maintenance, car wash
Saleries	
Saleries	worker salary, incentives
Depreciation / Interest on capital of assets	
Machinery / Vehicles	depreciation, interest on capital
Expenses for communication & electricity	
Expenses for communication & electricity	communication, electricity
Various Expenses	
Insurance of assets & equipment	insurance of vehicles

Transitions for Baseline

Transitions represent the processes described in previous sections. In order to implement the processes into the software environment the processes are simplified and abstracted. For modeling the baseline system, six transitions are specified (see Figure 10). As example for the baseline, the transition of block collection (BC) is presented as follows. Further transitions are similarly built up and thus, are described in Annex 1.1.

Each transition itself can be considered as a system with in- and output flows. The main in- and output of the transition BC is the waste that is transported to the municipal landfill. Basically, no transformation of the transport good takes place. Hence, the output remains the same material as the input. As shown in Table 18, only fuel and lubricants for compactor trucks are added as inputs. Input and output materials are defined by X and Y, respectively.

***Table 18**: In- and output flow are defined by different variables. The quantity of each flow for the transition of block collection is listed.*

Material	Variabel	Quantity	Unit
Input			
Fuel & lubricants	X02	114'374	l
Rejected waste	X03	4'192	t
Compostable waste	X04	7'785	t
Output			
Rejected waste	Y04	4'192	t
Compostable waste	Y05	7'785	t

Apart from in- and output flows the transition is determined by specific parameters as shown in Table 19. Parameters named with N are considered as net parameters and are valid for all transitions in the system, whereas parameters with C only belong to the respective transitions.

***Table 19**: Transition parameter for block collection.*

Name of parameter	Variabel	Quantity	Unit
Transport distance of truck per trip	C00	24	km
Velocity of truck (avarage)	C01	9	km/h
Working hours per day	C02	8	h
Volume capacity of truck	C03	13	m3
Density of waste in truck	C04	130	kg/m3
Fuel consumption of truck	C05	0.32	l/km
Attendance of truck	C06	65	%
Working days per year	N00	243	
Density of fuel (diesel)	N01	0.84	kg/l

Some of the parameter are based on data from section 1.1 or are self-explanatory. Others are briefly presented as follows:

- **Transport distance per truck**: This value is based on the measuring campaign conducted in 2004. The transport distances for trucks were measured.

- **Velocity of truck** is calculated from data given in section 1.1. According to Kubrom et al. (2004) the avarage transport distance of block collection vehicles is about 24 km. Furthermore, the average number of 3 trips per day was evaluated. Considering 8 working hours per day the average velocity of block collection trucks is about 9 km/h. More data on velocities of block and skip collection is given in Table 21.

- **Volume capacity of the truck** is an average value based on data from Kubrom et al. (Kubrom, Mehari et al. 2004).

- **Attendance of truck** represents the percentage of block collection vehicles that are operating during the year. In this case the attendance is set to be about 65%, which means that in average between 9 and 10 out of 15 vehicles are operating. At the time of investigation in 2004 only 11 trucks were operating. Hence, the assumption of 35% downtime[24] seems to be plausible. For comparison, in industrialised nations the downtime of collections vehicles is often less than 5%[25].

Based on defined input, output, cost plan and parameters the transition is specified. First of all, the relation between input (X03 and X04) and output (Y04 and Y05) is defined.
Furthermore, the transition is specified in order to calculate the number of block collection trucks. Each truck is assumed to be able to transport 800 t of waste per year. Due to required integer values for number of trucks, the relationship between number of trucks and capacity is not considered as linear.
The increase of the number of vehicles is therefore defined according to the step function as shown in Figure 11.

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[24] Downtime is the period of time a piece of equipment is out of order or shut down for maintenance

[25] Source: http://www.pima.gov/finance/bud0405/pdfs/t_pubwks/06_fs.pdf

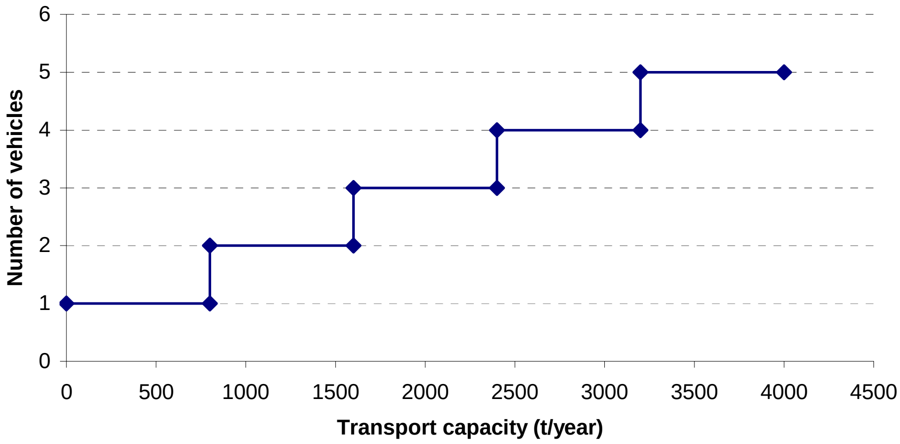
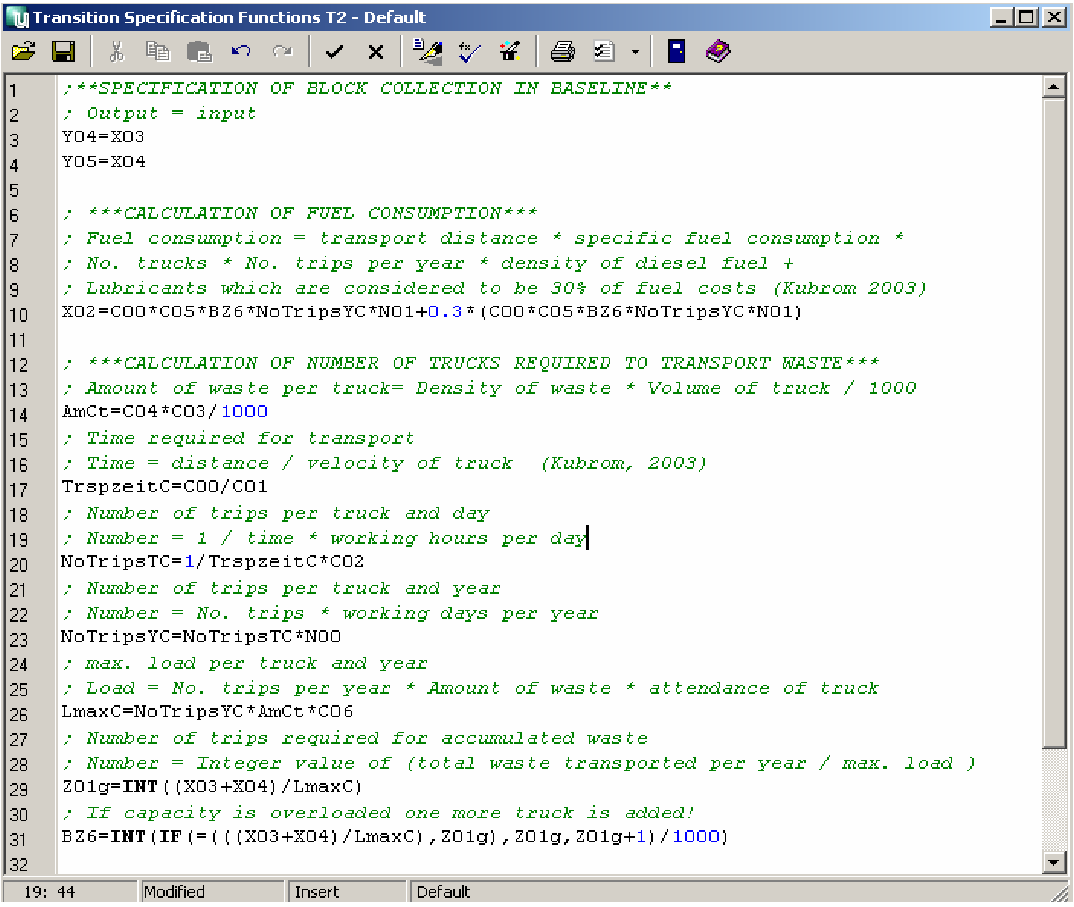


Figure 11: *Step function for number of vehicles. The number of block collection trucks depends on solid waste transport capacity.*

The fuel consumption (X02) is considered as a function of transport distance, specific fuel consumption, the densitiy of fuel, the number of trucks and the number of trips per year as described in Figure 12.



```
;**SPECIFICATION OF BLOCK COLLECTION IN BASELINE**
; Output = input
Y04=X03
Y05=X04

; ***CALCULATION OF FUEL CONSUMPTION***
; Fuel consumption = transport distance * specific fuel consumption *
; No. trucks * No. trips per year * density of diesel fuel +
; Lubricants which are considered to be 30% of fuel costs (Kubrom 2003)
X02=C00*C05*BZ6*NoTripsYC*N01+0.3*(C00*C05*BZ6*NoTripsYC*N01)

; ***CALCULATION OF NUMBER OF TRUCKS REQUIRED TO TRANSPORT WASTE***
; Amount of waste per truck= Density of waste * Volume of truck / 1000
AmCt=C04*C03/1000
; Time required for transport
; Time = distance / velocity of truck  (Kubrom, 2003)
TrspzeitC=C00/C01
; Number of trips per truck and day
; Number = 1 / time * working hours per day
NoTripsTC=1/TrspzeitC*C02
; Number of trips per truck and year
; Number = No. trips * working days per year
NoTripsYC=NoTripsTC*N00
; max. load per truck and year
; Load = No. trips per year * Amount of waste * attendance of truck
LmaxC=NoTripsYC*AmCt*C06
; Number of trips required for accumulated waste
; Number = Integer value of (total waste transported per year / max. load )
Z01g=INT((X03+X04)/LmaxC)
; If capacity is overloaded one more truck is added!
BZ6=INT(IF(=(((X03+X04)/LmaxC),Z01g),Z01g,Z01g+1)/1000)
```

Figure 12: *Transition specification for the process of block collection. Input and output relations are defined. The number of compactor trucks (BZ6) is calcaulated based on the amount of incoming waste (input).*

By using various parameters the number of trips per year and the attendance of these trucks, the amount of waste (LmaxC) that can be transported in a year by one truck is calculated.

The input devided by this value gives the number of block collection vehicles (Z01g) required. In case of a decimal result the number is transformed into the next higher integer value (BZ6).

The cost allocation is based on the the number of block collection trucks (BZ6) which serves as the cost driver in this transition. Activities performed are summarised to number of trips done per day. The number of trips per day, however, is directly related to the number of trucks as there is a fixed haulage capacity per truck. The higher the number of truck the higher the expenses are. Consequently, all expenses in this transition depend on the number of trucks.
Due to direct relation between cost driver and costs, all cost allocated are considered as proportional. Based on data from Kubrom et al. (2004) the proportional costs are calculated. The costs for the processes are allocated to various cost types according to the defined cost plan.
This means, due to modelling reasons, costs, which are commonly considered as fix, are allocated as proportional.

***Table 20**: Cost allocation in the process of block collection. The allocation is based on the specific cost driver BZ6 representing the number of trucks.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ6	55	Nkf/BZ6
Exp. auxiliary materials	BZ6	41'067	Nkf/BZ6
Exp. ext. service	BZ6	15'703	Nkf/BZ6
Salaries	BZ6	40'920	Nkf/BZ6
Machinery / Vehicles	BZ6	56'991	Nkf/BZ6
Insurance of assets	BZ6	1'291	Nkf/BZ6
Total costs	BZ6	156'027	Nkf/BZ6

Modifications for Centralised Composting System

In comparision to the baseline only a few modifications are done for the centralised composting scenario. As stated in section 3.4 centralised composting does not imply any change for collection and transport service. Hence, modifications for transitions are not required. The only change is the implementation of a centralised composting plant. Thus in the model the transition CC, the input place for water, as well as ouput places for compost, gas and water losses are connected.
The description for the transition CC can be found in Annex 9.3.6.

Modifications for Decentralised Composting System 1

Decentralised composting implies more changes in the model than centralised composting due to changes in waste collection and transport. In the first decentralised scenario only one more transition is inserted into the baseline model. Apart from that, parameters in various transitions and material flows are modified. In Figure 13 a scheme is illustrating the current waste collection principle (baseline) and the principle of collection as it is assumed to be for the scenario DC 1.

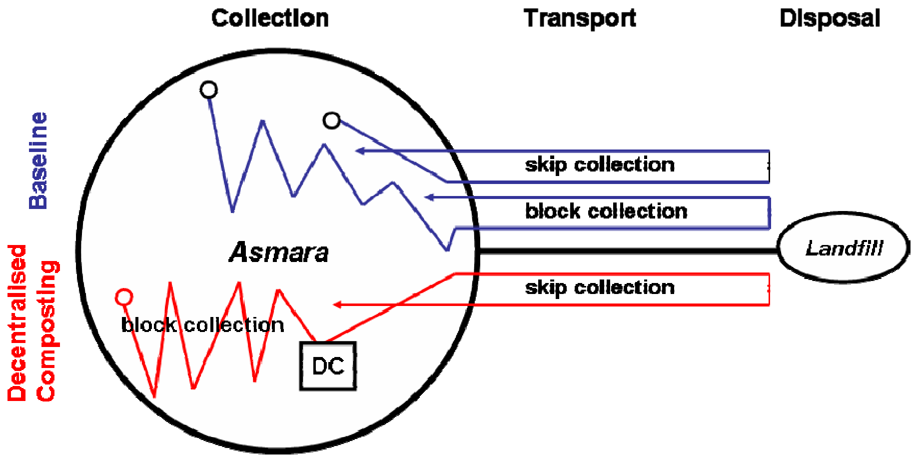


***Figure 13**: Schmematic description of current solid waste collection in Asmara (baseline) and as assumed after implementation of decentralised composting.*

For the baseline model velocities of block and skip collection vehicles are calculated. Transport and collection velocities are averaged as no practical separation exists.
In order to model the scenario of decentralised composting, the collection and transport of waste are defined separately.
In this study the collection represents all waste collection activities that take place within the city limit, whereas transport is considered as the transfer of waste from the city limit to the municipal landfill and back to the city limit.
In this scenario it is assumed that block collection vehicles collect waste and dispose it of at a nearby composting plant. This implies a change in the average velocity of block collection vehicles.
The new average velocity of block collection vehicles is derived from data given from the baseline model (see Table 21). According to Kubrom et al. (2004) block collection vehicles perform in average 3 trips per day with an average distance of about 24km. Based on own experiences the transport of waste outside of Asmara to the landfill and back, as well as a quick disposal of waste inbetween takes about half an hour[26]. Based on a working day of 8 hours, 1.5 hours per day are spent for transportation, whereas 6.5 hours are required for the collection of waste. Transport distance is taken as twice the

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[26] This assumption is based on the author's own experience by accompaning collection trucks in Asmara.

distance from Asmara to the municipal landfill, which leads to a distance of about 12km. Thus, the average transport velocity of block collection vehicles is about 24km/h. The remaining 12km are used for collection purposes. Taking this information into account an average collection velocity of 5.5km/h is resulting. This value is used as a new parameter for block collection vehicles in the decentralised composting scenarios 1. Velocities for skip loaders keep the value of 16km/h as there is no significant change in collection and transport.

***Table 21**: Average velocities for skip and block collection. Velocities are calculated out of collection characteristics based on one vehicle.*

Baseline **Skip collection**	**Total**	**Collection**	**Transport**	**Unit**
Trips / day	8			-
Distance / trip	16	4	12	km
Total distance / day	128	32	96	km
Working hours / day	8	4	4	h
Velocity	16.0	8.0	24.0	km/h
Block collection	**Total**	**Collection**	**Transport**	**Unit**
Trips / day	3			-
Distance / trip	24	12	12	km
Total distance / day	72	36	36	km
Working hours / day	8	6.5	1.5	h
Velocity	9.0	5.5	24.0	km/h

Apart from the velocity of block collection vehicles, collection and transport distances change. Currently, collection distances are about 12km. According to practical considerations, in average more than the half of this distance within the city limit can be additionally considered as transport activity and added to the transport distance. This means that during at least 6 out of 12km no waste is collected by block collection vehicles.

Decentralised plants spread all over Asmara give a lot of options for block collection to dispose of their collected waste. Therefore, the collection process only consits of collection. Thus, the collection distances, which are assumed to be lower than 6km, are set to be 5km.

Modifications for Decentralised Composting System 2

Compared with the decentralised scenario 1 only small modifications are made.

Within the transition TP, 50 skip containers are added. This number is likely to be enough to fulfill the demand for street sweepings as only in main streets second skips are provided.

Due to the additional skip containers, two types of skip collection are required. One is only responsible for the skip transport to the landfill. The other one is only operational within Asmara collecting skips with mixed waste and empying them at the composting plants. Similar to block collection the transport to the landfill is omitted and thus the transport distance per trip, as well as the average velociy of skip loaders decreases significantly.

As seen in Table 21 the collection velocity is about 8km/h. Transport distance per trip is assumed to be slightly higher than for block collection. This is due to the fact that few skips might be located outside Asmara. These assumptions, however, will be analysed according to their sensitivity in section 4.4.

4.2. Results of the Model

4.2.1. Process Costs

In order to cofirm the hypothesis mentioned in section 1.6 the results are analysed. If implementing decentralised composting, it is expected that the savings in collection and transport expenses are nearly keeping balance with the operational expenses for decentralised composting plants. In this section the results regarding expenses in the SWM systems are presented. If not indicated otherwise, all costs mentioned in this section are considered as operational costs (expenses) including depreciation and interest on capital for assets.

Overall Expenses

Basically, the Figure 14 indicates that implementing composting plants increases the cost of operation for the entire SWM system.
In the case of decentralised composting scenarios (DC1&2), the cost savings in collection and transport do not completely compensate for the operation costs of decentralised composting plants. Nevertheless, costs of operation seem to be partly compensated by savings in collection and transport of waste.
For the centralised composting scenario (CC), there is no significant compensation of costs as the collection system remains the same as in the current system (BL). In fact, the overall expenses of CC are in the same range as for DC 1&2.
Expenses for the BL are evaluated to be about 9.9 Mio. Nakfa per year. If not indicated otherwise, this amount will be the basis for further comparisons.

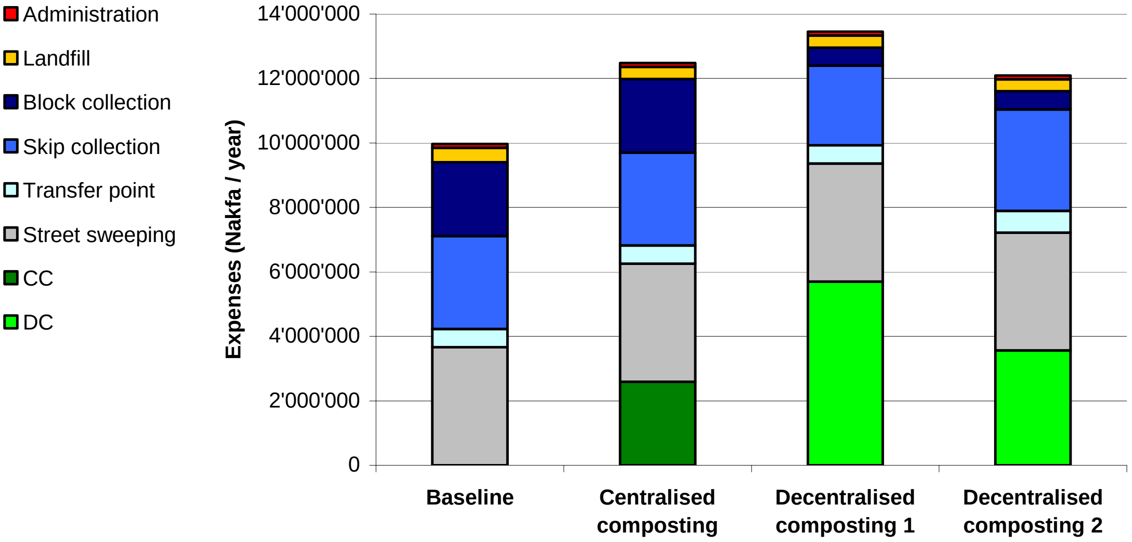

***Figure 14**: Overall costs for baseline and composting scenarios. Costs are illustrated according to processes.*

Based on the results, the implementation of a centralised composting plant leads to a cost increase of about 2.5 Mio. Nakfa (corresponds to about 25% of the current system). Savings of about 60’000 Nakfa at the landfill site due to reduction of waste disposal costs seem to be neglegible. Costs for collection and administration remain the same.
In the case of DC1, the increase of operational costs is higher due to high costs for plant operation. According to the results, the expenses for DC1 are about 13.5 Mio. Nakfa (+35%).
This indicates that the DC2 is less cost-intensive than DC1, as the increase of

costs for DC2 is calculated to be about 2.1 Mio. Nakfa (+21%). This is mainly due to a lower number of decentralised plants as shown in Table 22.

The lower number is due to the separation of street sweepings which leads to a lower demand of decentralised plants. Instead of 60 plants only 36 are required in order to process the incoming waste.

***Table 22**: Number of vehicles and plants for the four SWM systems.*

Number of vehicles / plants	Baseline	Centralised Composting	Decentralised Composting 1	Decentralised Composting 2
Block collection vehicle	15	15	5	5
Skip collection vehicle	6	6	6	8
Skip container	268	268	268	318
Centralised composting plant	0	1	0	0
Decentralised composting plant	0	0	60	36

In the BL, the processes of street sweeping, skip and block collection are the most expensive processes. They contribute to the overall expenses with about 36%, 28% and 22%, respectively. The expenses for the three other processes represent only 14%, altogehter. A detailed illustration is given in Annex 1.1.

Taking the CC into consideration, the expenses for collection and transport remain the same. The increase of costs is only induced by the operation costs for one centralised plant.

In the case of DC1, nealy 5.7 Mio. Nakfa are spent for operation of 60 composting plants. This corresponds to about 57% of the current system.

For DC2, the findings indicate costs of about 3.6 Mio. Nakfa for the operation of 36 decentralised plants. In both decentralised scenarios, the costs for plant operations are significantly reduced by cost savings in the collection processes as shown in the next section.

Collection & Transport Expenses

The results of this study indicate that transport and collection costs are decreasing after implementation of decentralised composting. The expected decrease is therefore confirmed.
Currently, the operational cost for collection (including transport) of solid waste to the municipal landfill is evaluated to be around 9.3 Mio. Nakfa. Consequently, the operational costs for collection in the centralised composting system are in the same range as there is no particular change in the collection system.
But the results in Figure 15 indicate a decrease of collection costs in DC1 and DC2 of about 23% and 14%, respectively.
Basically, cost reduction is mainly due to cost savings in block collection which are about 75% in both decentralised scenarios. Instead of 15 block collection vehicles only 5 are sufficient to fulfill the transport capacity in DC1&2. Skip collection is only reduced by 16% in the case of DC1. In DC2 skip collection even indicates an increase of costs as two more skip loaders are required.
Exept from DC2, transfer points, as well as the process of street sweeping do not contribute to any cost reduction as there is no change in activities compared to the current system.

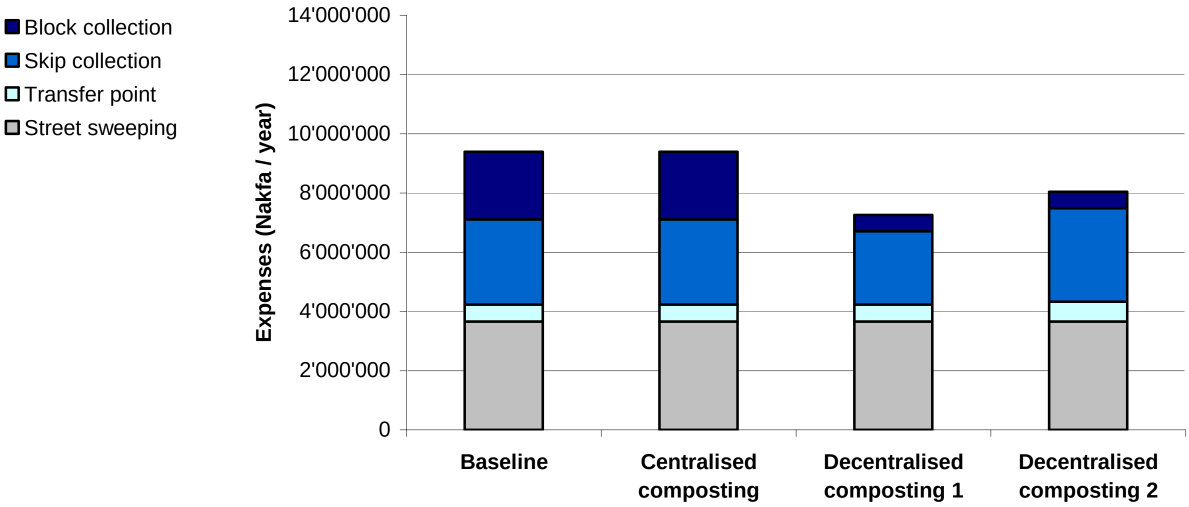

Figure 15*: Costs for collection processes. Block collection is significantly reduced implementing decentralised composting.*

4.2.2. Cost Types

Apart from process costs, the costs are presented according to cost types in order to give additional information of the system’s cost structures.

Initially, expenses for fuel and lubricants, as well as expenses for vehicles decrease for DC1&2 as shown in Figure 16. The results for fuel costs indicate a reduction of 49% and 41%, respectively. This is obvious as the collection and transport cost, mainly dependent on vehicles and fuel, decreased as well.

Consequently, for the case of CC, the cost for machinery and fuel are in the same range as the cost in the current system. The small difference is mainly induced through depreciation expenses for static equipment used for the set-up of one centralised plant.

In the BL about 3.7 Mio. Nakfa are spent for vehicles, such as for depreciation and interest on capital of 15 block collection trucks, 6 skip loaders, 1 front-loader and 268 skip containers. DC1 is the only scenario where vehicle costs are significantly reduced. With expenses of about 2.8 Mio. Nakfa in DC1 the costs for vehicles can be reduced by approximately 25%.

The main increase of operational costs in the composting scenarios is mainly due to increased expenses for labour. In the current system about 4.6 Mio. Nakfa are spent for working labour.

The implementation of CC induces an increase of salary costs of about 21%. In the case of DC1 and DC2 the salary costs even rise up to about 8.2. Mio. Nakfa (+78%) and 6.5 Mio. Nakfa (+41%), respectively.

Detailed tables of costs of all systems can be found in the Annex 1.1.

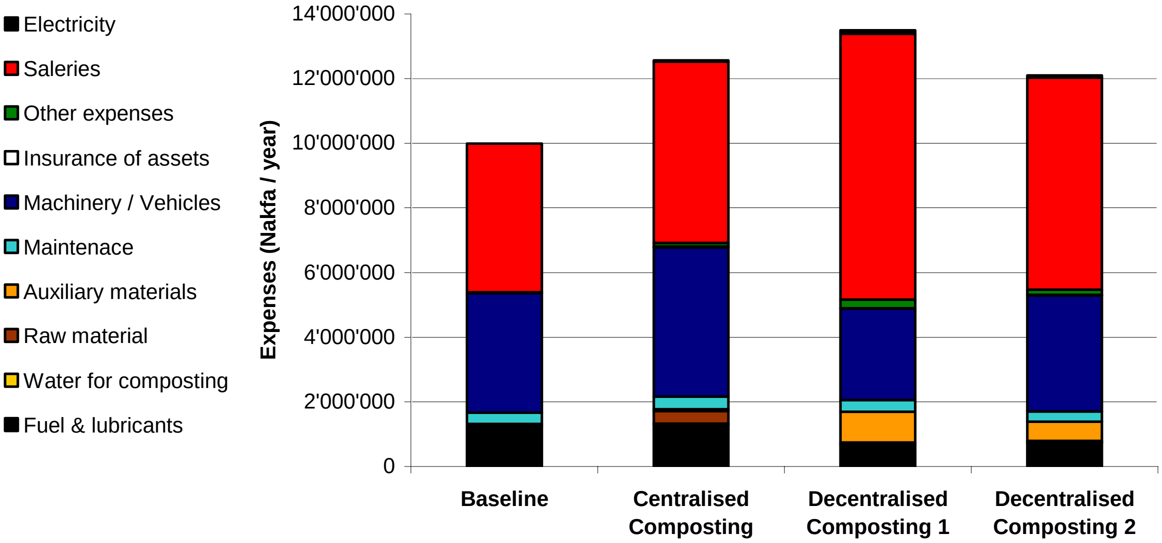

***Figure 16**: Overall costs for baseline and composting scenarios. Costs are illustrated according to cost types.*

4.2.3. Revenues

Based on the assumption that all compost is sold to a price of 20 Nakfa per m^3 the revenues are presented in Table 23.

Basically, the revenues which are expected from compost sales are negligible compared to the revenues currently received from service fees. The compost revenues are less than 1% of the total revenues.

Nevertheless, the revenues of 60’000 Nakfa from landfill material sale are likely to be doubled by selling high quality compost. The activities at the landfill remain the same and thus no change in revenues is expected.

Table 23*: Income for the baseline and the three composting scenarios. In the compostig scenarios the increase of revenues is negligible compared to the baseline.*

Income	Baseline	Centralised Composting	Decentralised Composting 1	Decentralised Composting 2	Unit
Service fees	12'282'145	12'282'145	12'282'145	12'282'145	Nkf
Landfill material sale	60'000	0	0	0	Nkf
Compost sale	0	116'800	116'800	116'800	Nkf
Landfill activieties	14'592	14'592	14'592	14'592	Nkf
Total income	**12'356'737**	**12'413'537**	**12'413'537**	**12'413'537**	**Nkf**

The results indicate that the expenses for current solid waste management are covered by the revenues. But the service fees also cover the service provided for liquid waste collection that is not included in this study. Based on that the total revenues seem to be low.

In case of CC and DC2 costs and revenues are nearly keeping balance, whereas DC1 is generating a deficit.

Especially, the revenues from compost sale seem to be underestimated as only around 2 to 4% of the costs for plants operation are covered. This could be on one hand due to conservative calculation of compost production or on the other hand based on low prices at which the compost is sold. According to a study (Zurbrugg, Drescher et al. 2004) in Bangladesh, compost sales alone cover 91% of the operation costs.

4.2.4. Comparable Units

The analysis of a system or process requires accepted criteria and units in order to give the opportunity of comparison. In waste treatment and/or disposal systems it is common to calculate comparable units, such as:

- cost per ton
- cost per ton kilometer
- cost per capita

Based on the results of this study these comparable units are calculated and presented in the following. The results are accompained by results of other studies which serve as a basis for comparison. The functionality and the local conditions in the solid waste management need to be considered when comparing various systems.

Cost per Ton

The costs per ton depend on the overall expenses and on the amount of waste collected by the SU. The amount of waste collected by the SU in 2003 is 44’364 tons of mixed waste per year. For the calculation of the specific cost the following formula is used:

$$C_{specific} = \frac{C_{tot}}{m_{tot}}$$

$C_{specific}$: Specific cost (Nakfa/ton input)
C_{tot}: Total cost per year
m_{tot}: Total amount of waste per year

The costs per ton are summarised in Table 24.
Due to the fixed amount of waste for all scenarios the relative changes only depend on the overall expenses and are thus the same as presented in the previous section.

***Table 24**: Cost per ton of mixed waste for the baseline and the three compsting scenarios.*

System	Baseline	Centralised Composting	Decentralised Composting 1	Decentralised Composting 2	Unit
Mixed waste	44364	44364	44364	44364	t
Total costs	9'994'611	12'563'463	13'500'259	12'100'587	Nkf
Cost per ton	225	283	304	273	Nkf/t

Considering absolute values, the results indicate that the costs for the current system are about 225 Nakfa per ton of waste. The most expensive system, DC1 generates specific costs of about 304 Nafka per ton. According to other studies, these values corresponding to 15$ and 20$ per ton of waste, respectively, seem to be in a plausible range.
Based on a study in India (Coad 1997) the costs per ton for refuse collection, without implementation of composting, are between 6$ and 12$. Rytz (Rytz 2001) stated values for a composting project in Bangladesh to be about 15$ per ton of waste (for collection and processing).

Cost per Ton Kilometer

The unit “cost per ton kilometer” represents the average costs which are generated by transportation of one ton over one kilometer. The cost per ton kilometer enables the identification of efficient transport and collection processes. In the following the formula for the calculation is shown:

$$C_{ton\_kilometer} = \frac{C_{process}}{m_{waste} \cdot km_{transport}}$$

$C_{ton\_kilometer}$: cost for per ton kilometer (Nakfa/ton/km)
$C_{process}$: Process cost per year
m_{waste}: Amount of waste per year transported
$km_{transport}$: The number of kilometer that the waste is transported

In Table 25 the cost per ton kilometer of the three collection processes used in Asmara are shown.
The results indicate that street sweeping is significantly cheaper than skip and block collection.
Furthermore, block collection seems to be the most expensive process with about 7.3E-4 Nakfa per ton kilometer.

Table 25: *Cost per ton kilometer of different collection processes in Asmara.*

	Block collection	Skip collection	Street sweeping	Unit
Process costs	2'291'147	3'445'087	3'663'000	Nkf
Amount of waste per year	11'978	32'386	17'745	t
Number of trips per year	10'935	11'664	395'604	-
Distance per trip	24	16	1.5	km
Distance per year	262440	186624	593406	km
Costs per ton kilometer	7.3E-04	5.7E-04	3.5E-04	Nkf/t/km

Nevertheless, if comparing these values of performance, the potentials and limitations of each process need to be considered.
Street sweeping seems to be the cheapest process for waste collection. But the transport distance is very limited as workers only walk for one up to two kilometers in order to dispose of their waste.
Further, the results indicate that the costs for skip collection per ton kilometer are 22% lower than for block collection.
However, it needs to be considered that skip collection is based on the performance of locals bringing the waste to the skip container. For block collection, as it is a house to house collection, locals do not need to transport their waste. This means that the collection type needs to be choosen based on the given conditions. A combination between street sweeping and skip collection seems to be very cost-effecient if participation of locals is considerd.

Cost per Capita

The cost per capital shows a relation between costs for operation of a system and size of population that utilises the systems service. In this study the cost per capita are calculated as follows:

$$C_{capita} = \frac{C_{tot}}{n_{population}}$$

C_{capita}: Cost per capita (Nakfa/capita)
C_{tot}: Total cost per year
$n_{population}$: Total size of population

The relative change between the results of costs per capita is the same as calculated for the costs per ton. As shown in Table 26, the costs per capita are lowest for BL and highest for DC1. Relative differences are the same as for cost per ton. However, this is obvious as the formla is similar.

Table 26: *Cost per capita for the baseline and the three composting scenarios.*

System	Baseline	Centralised Composting	Decentralised Composting 1	Decentralised Composting 2	Unit
Population	400'000	400'000	400'000	400'000	inhabitants
Total costs	9'994'611	12'563'463	13'500'259	12'100'587	Nkf
Specific costs	25	31	34	30	Nkf/capita

According to these results, currently about 25 Nakfa (around 1.7$) need to be spent yearly by locals for the municipal solid waste collection service. Studies in India[27] stated values for cost per capita of around 1.5$. Thus, the values in Asmara seem to be comparable.

4.2.5. Material Flows

Apart from changes in the cost structure of the SWM, the implementation of composting has a significant impact on the material flows. As for example transportation costs strongly depend on the amount of waste due to the direct relation between number of vehicles required and waste to be transported.
In figures Figure 17 and Figure 18 the waste flows are presented for the baseline (BL) and for decentralised composting scenario 2 (DC2). They are presented as Sankey-diagrams, where the thickness of the arrow is directly proportional to the mass flow. The illustration of the two other scenarios is given in Annex 9.4.

The input of the system is mixed waste generated by the households, industries ect. (Generation).
Within the transition that is not specifically described, as only being relevant for modelling purposes the compostion of waste is defined. Mixed waste is split into rejected waste and compostable waste.
In particular, the system shows that the amount of waste collected by street sweepers is in the same range as for block collection. Skip collection seems to be the process with the highest capacity. In total about 44’364 tons of waste are collected and transported to the landfill.
The waste flow going to the TP not collected by a defined process represents the amount that is collected by locals. About one third of the total waste is brought to the skip containers without generating any expenses for the municipality. Based on this result, the performance of local has an important role in waste collection and needs to be considered for planning new SWM systems.
Furthermore, the figure reveals that there is a huge amount of compostable material which is transported to the landfill. According to Table 27 about 17’300 tons of compostable waste is finally disposed of at the landfill.
Gas and water losses are significant, but are not discussed any further as more detailed information is needed. Within the time frame of this study, this aspect had to be excluded.

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[27] Source: http://www.exnora.org/swm.html

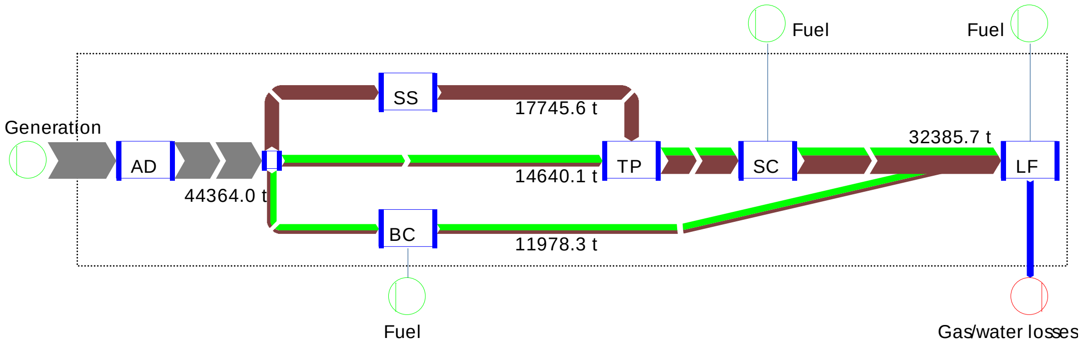

***Figure 17**: Sankey-diagram for the baseline system. Different waste flows are represented by differnt colors; mixed waste (grey), rejected waste (brown) and composable waste (green). Other flows are illustrated as follows; gas & water emissions (blue) and landfill material (yellow).*

In the figure for the DC2, the observation reveals that there is a large reduction of waste that has to be transported to the landfill. As shown in Table 27 the results indicate a reduction of about 35%.
Mainly compostable waste is reduced as it gets degraded at the composting plant. Uncontrolled disposal of organic waste is therefore reduced.
The findings in this study show that compostable waste going to the landfill is reduced by about 90%.

***Table 27:** Amount of solid waste transported to the municipal landfill, currently and after implementation of composting.*

Baseline & Centralised composting		**Quantity**	**Unit**
Block collection	Rejected waste	4'192	t
	Compostable waste	7'786	t
Skip collection	Rejected waste	22'870	t
	Compostable waste	9'516	t
	Total	44'364	t
Decentralised composting			
Skip collection	Rejected waste	27'062	t
	Compostable waste	1'730	t
	Total	28'792	t

In the decentralised composting system, block collection is only operational between housholds and decentralised composting plants. The waste transport to the landfill does not take place.
Due to separation of street sweepings, the incoming waste at the composting plants mainly consits of compostable waste. This leads to a higher efficiency of the plants as only a small amount of rejected waste goes to the landfill.
Based on the results the amount of compost produced is in the range of the current amount of landfill material sold.

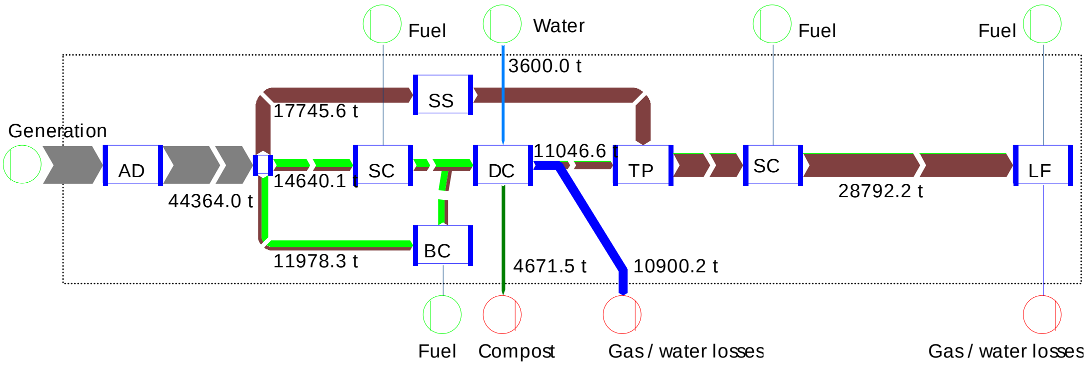

Figure 18: *Sankey-diagram for decentralised composting system 2. In this scenario decentralised plants (DC) are implemented. Flows are illustrated as described for the baseline and centralised composting system. Street sweepings (SS) are not treated by decentralised plants.They are directly transported to the municipal landfill (LF).*

4.3. Scenario Analysis

4.3.1. Basic Assumptions

The results indicate an increase of costs if composting is implemented. In decentralised systems, this is due to the fact that cost reduction from waste transport is not keeping balance with the increase of cost for operation of plants.
But these results are only representing the current situation in Asmara. The situation in Asmara is likely to change in the mid-term future. The population of Asmara might increase resulting in an increase of waste generation. Habtetsion et al. (Habtetsion, Ghirmay et al. 1999) stated increases for solid waste generation of 8% per year.
However, this would lead to changes in the waste management. In this section a realistic scenario is presented.
Of course, Asmara's municipal landfill will be filled one day and the municipality is therefore forced to find another location for waste disposal. The transport distance to the new disposal site is likely to be more than 6km due to lack of appropriate places close to the city.
The increase of transport distances is accompained by an increase of overall costs of the municiplal SWM.
In case of having longer transport distances, the implementation of decentralised composting is expected to be more viable due to higher savings in transportation. The following analysis is therefore conducted in order to evaluate the break point distances where the costs of the different systems are keeping balance.

In order to evaluate this distances parameter need to be varied within the transitions of the model. Basically in the baseline and the centralised system, only skip and block collection would be influenced by increasing the transport distance to the landfill. In the case of decentralised system only the skip collection would change, whereas block collection is not affected as it is only operational between housholds and composting plants.

4.3.2. Break Point Distances

In order to model the increase of transport distances two parameters in the respective transition are varied. Of course, the total transport distance changes, but also the parameter of the average velocity. Due to longer transport distances the average velocity increases. In Table 28 the variation of parameters are presented based on different transport distances to the new municipal landfill. The total distance per trip is the sum of twice the distance to the landfill and the respective collection distance (see Table 21). The collection distance remains fix as there is no change within the city limits.

***Table 28**: Total distance per trip and average velocity based on different transport distances (Asmara to the landfill).*

Parameter	**Distance to landfill**				
Skip collection	**6 km**	**15 km**	**20 km**	**30 km**	**40 km**
Total distance / trip	16	34	44	64	84
Velocity (Average)	16	19.4	20.3	21.3	21.9
Block collection					
Total distance / trip	24	42	52	72	92
Velocity (Average)	9	12.2	13.5	15.4	16.7

As shown in Figure 19, the distances to the landfill have significant effects on the overall expenses for SWM in Asmara.

The results indicate that a transport distance increase of 9 km or rather 14 km leads to an overall cost increases of 53% and 86%, respectively.

The increase for centralised system seems to be parallel to the baseline system as there are no cost savings in transportation. But for decentralised systems, the findings demonstrate enhanced cost savings for longer transport distances.

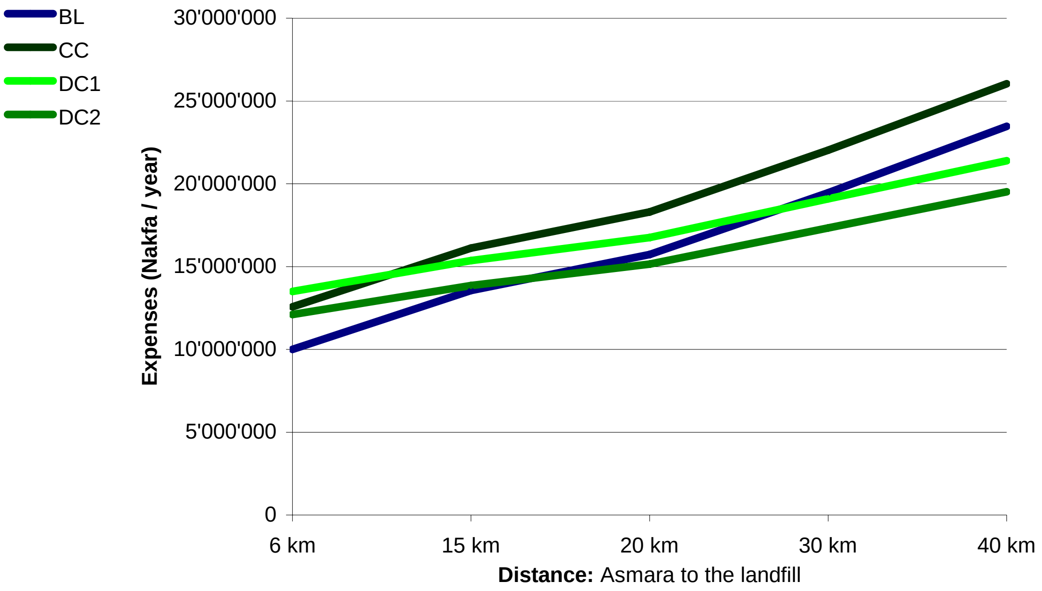

***Figure 19**: Expenses for SWM in Asmara depending on the distance to the landfill. The baseline system (BL) is compared with three composting scenarios: centralised composting (CC) and decentralised compsting 1&2 (DC1&2).*

As mentioned before, at the point of 6 km distance (current situation), the composting systems are more expensive than the baseline. But considering transport distances of about 17 km, the costs for the decentralised system 2 are keeping balance with the baseline system. Distances over that break point even indicate higher expenses for the baseline system.

The comparison between composting scenarios even indicates that for transport distances over 13 km the costs for a decentralised system are lower than for a centralised system.

The analysis of distances over 30km seems to be unrealistic. But in case of Bouargoub in Tunisia (Walid 2004) a centralised plant is planned to be built in a distance of more than 30km.

Other projects are known where the distance to the plant is more than 50km[28]. Thus, the analysis of distances up to 40km seems to be justified.

4.4. Sensitivity Analysis

Models serve as support to understand complex systems and their relation. Basically, they are used to gain information on qualitative and quantitative relations. But often, system parameters of a model are unknown and therefore assumptions have to be used. Hence, based on a set of unknown parameters, model results are hard to evaluate.

In order to improve the model's results the structure and the parameters have to be optimised.

If target figures are known, the model needs to be calibrated. This means, to modify the parameters so that the models results are corresponding to the known target figures.

In order to know the models reliability, the structure and thus the parameters have to be analysed. The most sophisticated approach would be to carry out a detailed sensitivity analysis. It is a systematic and comprehensive test to evaluate how changes in the parameters of a model affect the model's result[29].

However, due to lack of computer-aided simulation methods[30] and lack of time for a detailed manual analysis, only a local sensitivity analysis is conducted. For that, based on a set of parameters each parameter is varied. The other parameters are kept as basic values in order to quantify the resulting change in the output based on one parameter. Parameters having a large influece on the results need to be chosen accurately.

Based on the model used in this study, this pragmatic senstitivity analysis is carried out. Basically, the analysis is based on defined target figures. In this study financial evaluation is of highest priority. Thus the overall expenses of the SWM are considered as a target figure. Furthermore, in a second analysis the compost flow is taken as a target figure in order to see the influence of specific parameters on the production of compost.

4.4.1. Parameter Uncertainity

In this analysis the sensitivity of operational costs in the baseline system is analysed. For that the costs of 9.9 Mio. Nakfa per year serves as the target figure based on the current set of parameters. In order to evaluate the influence on the result each parameters of the baseline model is seperately changed by 5%. As a general approach 5% is considered as the range of uncertainity of each parameter. Therefore the analysis is carried out based on that value. The results are presented in Table 29.

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[28] Source: Personal communication with Silke Drescher, expert in sanitation issues in developing countries.

[29] Source: www.ameteam.ca/glossary.html

[30] Umberto 5.0 is not supporting a sensitivity analysis (Monte-Carlo-Simulation) according costs

Table 29: *Sensitivity analysis for baseline costs. Parameters of block and skip collection are evaluated.*

Parameter for block collection	**Unit**	**Basic value**	**Decrease**	**Change in SWM costs**	**Increase**	**Change in SWM costs**
Transport distance per trip	km	24	-5%	-1.4%	5%	1.6%
Velocity (average) of vehicle	km/h	9	-5%	0.7%	5%	-1.3%
Working hours per day	h	8	-5%	0.7%	5%	-1.3%
Volume capacity of vehicle	m3	13	-5%	0.7%	5%	-1.3%
Density of waste	kg/m3	130	-5%	0.7%	5%	-1.6%
Specific fuel consumption	l/km	0.32	-5%	0.0%	5%	0.3%
Attendance of vehicle	%	65	-5%	0.7%	5%	-1.6%
Parameter for skip collection	**Unit**	**Basic value**	**Decrease**	**Change in SWM costs**	**Increase**	**Change in SWM costs**
Transport distance per trip	km	16	-5%	-1.4%	5%	4.8%
Velocity (average) of vehicle	km/h	16	-5%	4.5%	5%	0%
Working hours per day	h	8	-5%	4.5%	5%	0%
Volume capacity of vehicle	m3	7	-5%	4.8%	5%	0%
Density of waste	kg/m3	380	-5%	4.8%	5%	0%
Specific fuel consumption	l/km	0.32	-5%	-0.3%	5%	0.3%
Attendance of vehicle	%	90	-5%	4.8%	5%	0%

Observation of changes indicate that parameter from skip collection have a larger influence on the overall expeses than from block collection. This is not due to the transition’s structure, but due to the fact that skip collection is more expensive. Therefore, changes in skip collection contribute more to changes in the entire system than comporative changes in block collection.

As an exeption there is no change the overall costs of the baseline if increasing some of the parameters in the skip transition. This is due to the fact that the change of parameter is not leading to an additional cost driver (skip loader) and therefore no change is occuring.

Basically, the analysis indicates that the accurancy of specific fuel consumption is not as relevant as other parameter in the specifications.

Apart from fuel comsumption, all parameters seem to have a large influence on the outcome of the model. A parameter change of 5% leads to a change in costs up to 4.8%. This demonstrates, however, that these parameters need to be choosen carefully in order to generate reliable results.

Anyway, the analysis only includes parameter for the collection processes and should not be overestimated.

Each parameter used in the baseline model is also used in the structure of the centralised and of both decentralised models. Based on further analysis the results indicated that the relative change of each parameter is smaller and therefore not of importance.

4.4.2. Change in Waste Composition

Despite of expecting only a little impact on costs, the effect of waste composition on a decentralised system is analysed. According to Habtesion et al. (1999) the waste in Asmara contains 52.2% organics and 12.9% paper and cardboard. Thus, 65% was considered as compostable waste in this study.

In the scenario of decentralised composting a reduction of 20% in the organic content implies an increase of overall costs for SWM of about 0.5%. This is mainly due to the fact that composting plants in this model are dimensioned according to the total waste to be processed independent from organic waste contents.

In contrast to the change in overall costs, the waste composition has a huge impact on the production of compost. According to this study the organic content in the waste is directly proportional to the amount of compost produced. A reduction of 20% in the organic matter leads to a compost production decrease of 20%. This is not surprising, but shall be mentioned as it is important for dimensioning composting plants and further the entire SWM system.

4.5. Uncertainity Analysis

Based on the sensitivity analysis the range of uncertainity is assessed. Due to lack of small data base, the analysis can not be based on an empirical approach. The approach of assuming 5% uncertainity for each parameter is rather pragmatic than sophisticated, but it serves as basis for further information.
Based on the parameter uncertainity the lower and upper limit of costs for the baseline and the scenarios is evaluated. In order to achieve the respective limits, each parameter is reduced or increased by 5% within the same calculation process. In Figure 20 the results are presented.

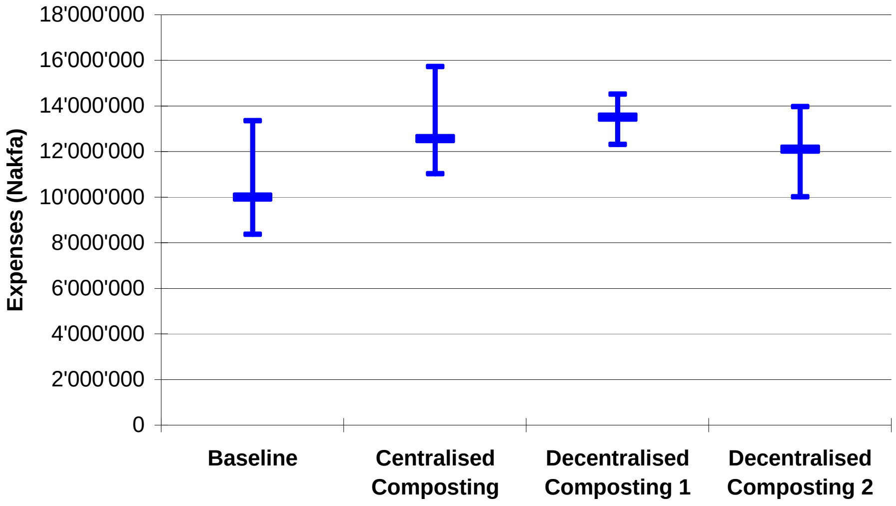

***Figure 20**: Uncertainity interval for the baseline model and all composting scenarios. The analysis is based on a parameter uncertainity of 5%.*

The results indicate that the range of uncertainity is different for each scenario. Especially, the range for the decentralised composting scenario 1 (DC1) is significantly smaller than for the baseline (BL) and the centralised composting scenario (CC). The difference can be explained as the overall costs for the DC1 are not as much dependent on collection costs as the BL and the CC. Most of the costs in the DC1 are due to operation of decentralised plants and therefore not influenced by the collection processes.
Based on this analysis it is likely to see that the cost differences between BL and DC1 are significant. Furthermore, the results demonstrate that DC2 tends to result in lower costs in comparision to the other scenarios. But the difference does not seem to be significant.
Anyway, the analysis does not include all relevant assumptions and the expressiveness is therefore limited. Due to lack of time different assuptions are not considered as discussed in the following section.

5. Discussion

5.1. Data Accuracy

Data accuracy is already partly adressed in section 4.4. But only some of the parameters are analysed. Some of the basic assumptions are not defined as parameters and therefore not included in the analysis. These basic assumptions need to be discussed in order to evaluate the significance of the study's results.

5.1.1. Baseline System

The main results consit of comparison of baseline systems and the three alternative scenarios.

Basically, the three alternative scenarios presented in this study are based on the structure of the baseline model. However, this seems to be a reasonable approach due to serveral reasons.

Data of the current system is available from the SU report and thus seen as relatively accurate. Furthermore, the system efficiency in alternative scenarios is likely to be the same as there are not many changes in the collection processes. Modelling completely new structures in the SWM in Asmara would be difficult to evaluate and therefore hardly believable.

Basically, the baseline system seems to generate reliable results. The costs per ton of about 15$ are in the same range as for other systems in developing countries[31] (Coad 1997). Some other comparisons are already done in section 4.2 and are not repeated. Apart from that, the results of the model seem to be similar to the data given in the SU report.

These facts, however, are not a warranty for a detailed representation of the current system. Nevertheless, the results indicate that the model is feasable to reproduce the data of interest closely corresponding to data in the case study report.

5.1.2. Composting Scenarios

A reliable representation of the current system does not automatically lead to reliability of composting scenarios. Modelling composting scenarios implies the use of data, which is coming from various sources. Considering the composting scenarios in this study, data for investment and operation costs of new assets were difficult to evaluate.

The experience made by other authors (Kashmanian and A.C. 1989) is that collecting and summarising cost data from different composting plants and facilities possibly leads to missleading and unreliable conclusions. Costs of composting facilities in different countries are hardly to be compared due to different reasons, such as local conditions, variation in size, method of operation, plant complement, number of shifts and other financial details. Anyway, the cost assumptions for the plants used in this study were mostly evaluated by experts and therefore taken as reliable.

A basic problem occurs by comparison of the baseline system with the composting scenarios.

In the baseline system depreciation and interest on capital were calculated based on the existing vehicle fleet in Asmara. Some of the old vehicles still operational are considered as amortised. But for composting plants, the imputed costs were calculated based on new assets. Comparing the depreciations of an old collection vehicles fleet with new composting plants might lead to underestimation of vehicle costs resulting in underestimation of cost savings in decentralised composting scenarios.

In contrast, in the case of centralised composting, the costs for plant purchase and additional assets, such as a front loader are not considered due to differ-

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[31] Source: Personal communication with Ch. Zurbrugg, expert in sanitation issues in developing countries (zurbrugg@eawag.ch)

ent reasons mentioned in section 3.4. These assumptions could be questioned and therefore further investigations on site are required.

Another point to be mentioned is the level of worker salaries. In this study salaries for plant workers are set to be in the range of salaries for street sweepers. As already discussed, these salaries are low, but correspond to figures of already existing plants (Bushan and Anish 1997). However, it is important to mention that an increase of salaries for plant workers implies a significant increase of overall costs for all composting scenarios. In the planning phase of a decentralised plant the salaries should therefore be an important issue to be discussed.

As costs strongly depend on material flows, the amount and compostition of waste used in this study needs further discussion.
The exact amount of waste is important for calculation of specific costs in the baseline and for comparison of scenarios. Basically, as the data is based on a new measuring campaign in 2004 recorded by the SU, the quantities used in this study do not need further questioning. But the quality or composition of waste needs to be addressed.
The compostion of waste used in this thesis is based on a study (Habtetsion, Ghirmay et al. 1999) from 1999. The organic fraction is stated to be about 65% within the solid waste. But the composition most probably changed within the last few years. The organic fraction is likely to be reduced due to increased use of plastic and other inorganic materials. A futher study on the waste composition representing the current situation would therefore lead to more accurate results.
Basically, the composition of the waste determines its density. The more organic matter within the waste the denser it is. In this study an average density of waste was taken into account in order to calculate the waste haulage for each collection process. In case of composting the waste gets separated. The organic fraction is sorted out and therefore the waste density decreases. As the volume capacity per trip remains the same, the desitiy decrease leads to a lower amount of waste which gets transported per trip. But due to lack of specific data the density change after separation is not considered.

After reading this section a lot of doubts on the feasibility of the analysis might be raising. But the analysis serves as first step towards the evaluation of implications of decentralised composting in developing countries and still needs to be extended.
The improvement and extension of the model, as well as the application to other case studies should give the possibility to provide more accurate information on that topic. Nevertheless, unregarding the uncertainities the study provides results that serve as a basis for further discussion.
In the following section the baseline, the centralised and the decentralised system are generally evaluated regarding economical limitations and potentials of each system.

5.2. The current System versus Composting Systems

Apart from the financial analysis as done in this study the aspects of centralised and decentralised composting shall be discussed regarding economical implications of composting. The following discussion is based on the situation in Asmara, but several points are valid also for many other developing countries.
Despite of tending to result in higher expenses, composting, especially decentralised composting, can lead to economical benefits for the local authorithies, as well as for the local population.
The extension of the landfill lifespan could be extended significantly, as 35% of the waste is reduced after implemention of composting (see section 4.2.5). Based on the fact that there is no management on the municipal landfill at the moment, these cost savings are negligble. But in the nearby future a management might be required and therefore significant cost saving could be ex-

pected.

Apart from others, the consumption of land resources can be considered as environmental costs[32] which are not included in this study. Consumption can be considered as the use of land for waste disposal or the land contaminated by hazardous landfill material. The application of hazardous landfill material is hard to evaluate, but could also be accounted as environmental costs. Accumulation of heavy metals in soil (Drescher and Tesfay 2005) might lead to long-term effects that need further attention.

In the current system contaminated water from leachate is not treated. At a certain point, the contamination of soil and water can not be accepted anymore and appropriate treatment options need to be applied. These treatments are resulting in high-cost procedures. If implementing composting a significant part of these costs can be avoided. Environmental protection, as well as human health needs to be the major interest of each policy. The consideration of environmental costs should therefore be a nessecity and included in further studies.

In the case of greenhouse gas production, some projects, certified as Clean Development Mechanism (CDM) projects, avoiding or reducing the generation of greenhouse gases are already internationaly funded due to the global effect of greenhouse gases.

Having the potential of reducing greenhouse gas emissions, composting is therefore able to be partly covered by international fundings. According to a study (Lüthi 2005) on CDM mainly centralised plants are considered. Nevertheless, the implementation and sustainability of a SWM system should not depend on international fundings.

In contrast, the SWM should be sustainable based on local resources. And this seems to be the potential of decentralised composting. The implementation of decentralised composting is likely to be feasable without imported machinery. Being based on low-technology, the implementation, as well as the maintenance can be done by local people.

Operation of several decentralised plants is cost-intensive due to the expenses for labour. But spending money on salaries is likely to generate an added value within the local economy. Due to the employment of mostly unskilled and poor people, decentralised composting can be seen as an approach towards poverty alleviation.

But apart from a direct positive influence on the regional economy, decentralised composting reduces the bottleneck of the current system. The cost-intensive and partly inefficient vehicle fleet can be reduced significantly.

This means, fewer vehicles need to be imported. And considering the municipal means in foreign currency and the inflation of the Nakfa, importing assets seems not preferable. These aspects do not include external investments as it is assumed that all investments are covered by the municipality.

In this study the availability of a market is taken for granted as landfill material is already sold to local farmers. The price of compost is derived from the price from landfill material, but seems to be low. The revenues from compost sale only cover a small part of the expenses for the operation of the plants. These results are not good preconditions for a sustainable operation of the plants. Anyway, the sustainability of a composting system is mainly based on the existing market. These aspects are already part of other studies and are therefore not discussed any further (Mansoor 2004), (Kashmanian and Spencer 1993), (Zurbrugg 2002).

However, the above mentioned aspects being part of an integrated appraoch should be considered in desicion-making and planning of SWM systems.

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[32] Source: http://www.epa.gov/opptintr/acctg/pubs/busmgt.pdf

5.3. Modelling Approach

The approach of representing the SWM systems required several modeling steps. At the beginning only crude data was availble describing the current system. Indeed a lot of data was summarised, but the understanding of the SWM system was still limited. By definition of system boudaries useful data could be extracted and used for iterative built up of the model.

There was still missing data, such as attendance time of collection vehicles in Asmara, which could not be found in literature or assessed in interviews. But by using the software-tool, the model was able to provide the missing data after calibrating the model. Missing data was therefore evaluated by the principle of “trial and error” and then verified according plausibility.

This approach is a very pragmatic way of modelling a system. Nevertheless, it helped understanding the system, the parameters used and the data implemented.

The diffictulty of modelling the system was to keep the model as general as possible. Keeping the model general required the definition of various parameters. The application to other systems should therefore be possible by simply changing the parameter in each transition.

By modelling the scenarios the general character of the transitions was partly verified as transport distances and average velocities are varied within certain transitions. But the use in other case studies still needs to be tested.

6. Conclusions

In the following are some of the main conclusions that can be drawn from this study.

6.1. Composting as a Option for Asmara

- Implementation of composting results in higher expenses for the SWM in Asmara. Based on the current expenses of nearly 10 Mio. Nakfa, the implementation of composting leads to a significant cost increase. The cost increase seems to be similar for centralised and decentralised systems. The results indicate an increase of 25 to 35%.

- In case of decentralised composting the cost for collection and transport can be reduced significantly. The study's results indicate a reduction of 14 to 23%.

- The feasibility and profitability of decentralised composting strongly depends on the transport distance to the landfill. The longer the distance the more viable it is to implement decentralised composting. The study in Asmara shows that for a distance between 17 and 27 km the costs for the current system and the decentralised system are likely to be the same.

- Composting systems in Asmara could provide work for about 100 to 400 additional plant workers. Especially decentralised systems are very labour intensive and therefore a basis for employment generation. And due to the requirement of unskilled labour mainly poor people are addressed. Thus, it can be seen as an approach towards local poverty alleviation.

- The implementation of decentralised composting leads to a decrease of cost for machinery and vehicles. In contrast, based on the current expenses of about 3.7 Mio. Nakfa for machinery and vehicles, the centralised system results in an increase of around 24% given the necessary machinery of the composting plant. Considering the disadvantages of importing machinery and vehicles, the decentralised option seems to be preferable.

- Based on a compost price of 20 Nakfa per m^3 the sales do not significantly contribute to the total revenues of the SWM which are dominated by services fees. The compost revenues are less than 1% of the total revenues. However, the revenues from compost sale double the current sale of landfill material.

6.2. Model Application

- The model seems to be feasible to represent the current SWM in Asmara regarding material flows and costs. Based on the model results the cost transparency of the current system and alternative scenarios is improved. This can serve as a basis for strategic planning for investments in the SWM in Asmara.

- Due to the variability of input flows and parameters, the model enables the application to other case studies. Especially the representation of different collection systems is facilitated.

7. Outlook

This study is mainly focused on the situation in Asmara, but did not include all aspects which are relevant for an overall assessment regarding economical implications of composting.
The savings that are based on a reduced waste disposal are not completely considered in this study. The extension of the landfill lifespan is likely to have a significant effect on the overall SWM costs in the future and needs to be approached in a further assessment.
However, the developed model for Asmara can be improved by primary data collection instead of approximation by expert judgement and model calibration. In addition, the model can be improved assessing the most relevant factors of the SWM system on site. To determine such factors the model needs to be analysed in more detail involving a sophisticated sensitivity and uncertainity analysis.

This study serves as step forward to evaluate the implication of decentralised composting in developing countries. Obviously, the case study analysis does not allow any general outcomes.
In order to provide broader information on that topic the study needs to be extended. This is achieved by the inclusion of more case studies.
Currently, based on the situation in Bouargoub (Tunisia) the same approach is used to represent the current SWM and alternative composting scenarios. Other studies should follow in order to have comparable results.
The level of detail and scope of the analysis should be improved by taking other economical aspects into account.
Resource consumption is a relevant aspect in this kind of financial evaluation. The land required for waste disposal, the water polluted by the organic load resulting from inappropriate landfill management and other aspects need to be considered and therefore transferred into monetary units. Thus, it is important to include environmental costs in future studies.

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9. Annex

9.1. Depretiation & Interest on Capital for Baseline System

***Table 30**: Depreciation and interest on capital for the baseline system. Calculations are done according to the formulas in section 2.1.2.*

Vehicle	Year	Quantity	Unit cost	Total cost	Useful years	Rate of interest	Depreciation	Interest on capital
						%	Nakfa	Nakfa
Compactors								
Mitsubishi (15 m3)	1996	2	1'484'250	2'968'500	5	6	445'275	114'499
Mitsubishi (12 m3)	1998	2	507'267	1'014'534	5	6	152'180	39'132
Mitsubishi (5 m3)	1998	2	288'140	576'280	5	6	82'326	22'228
Old trucks	-	9	120'000	1'080'000	-	6	-	41'657
Sub total		15		4'559'314			**679'781**	**175'859**
Skip loaders								
Mitsubishi (10 t)	1996	4	2'547'100	10'188'400	5	6	1'528'260	382'065
Mitsubishi (10 t)	1998	2	523'500	1'047'000	5	6	157'050	39'263
Sub total		6		11'235'400			**1'685'310**	**421'328**
Wheelbarrow		407	500	203'500	5	6	**30'525**	**7'631**
Skip container		268	23'000	6'164'000	15	6	**308'200**	**231'150**
Loader		1	1'287'800	1'287'800	5	6	**193'170**	**48'293**
Waste separator	**-**	1	716'000	716'000	15	6	**35'800**	**26'850**
Sieving machine		1	716'000	716'000	15	6	**35'800**	**26'850**

9.2. Cost Summaries

9.2.1. Cost Summary according to Processes

***Table 31**: Process cost for each SWM system.*

Process	Baseline	Centralised composting	Decentralised composting 1	Decentralised composting 2	Unit
DC	0	0	5'699'800	3'559'880	Nkf
CC	0	2'588'318	0	0	Nkf
Street sweeping	3'663'000	3'663'000	3'663'000	3'663'000	Nkf
Transfer point	566'284	566'284	566'284	671'934	Nkf
Skip collection	2'878'803	2'878'803	2'474'003	3'148'803	Nkf
Block collection	2'291'147	2'291'147	558'708	558'708	Nkf
Landfill	450'212	371'588	371'588	371'588	Nkf
Administration	124'053	124'053	124'053	124'053	Nkf
Total	**9'973'499**	**12'483'193**	**13'457'436**	**12'097'966**	**Nkf**

9.2.2. Cost Summary according to Cost Types

***Table 32:** Cost accounted according cost types for each SWM system.*

Costs	Baseline	Centralised Composting	Decentralised Composting 1	Decentralised Composting 2	Unit
Amount of waste generated					
Mixed waste	44'364	44'364	44'364	44'364	Nkf
Expenses Materials					
Fuel & lubricants	1'253'980	1'289'544	645'244	732'782	Nkf
Water for composting		33'927	41'504	22'969	Nkf
Raw material	12'475	385'428	56'645	38'725	Nkf
Auxiliary materials	52'778	66'349	952'778	592'778	Nkf
Expenses for services					
Maintenace	344'506	390'459	359'010	310'614	Nkf
Depreciation / Interest on capital					
Machinery / Vehicles	3'699'533	4'610'315	2'828'261	3'593'869	Nkf
Various Expenses					
Insurance of assets	28'402	28'386	14'790	16'725	Nkf
Other expenses		113'996	270'000	162'000	Nkf
Saleries					
Saleries	4'599'997	5'610'634	8'219'288	6'561'305	Nkf
Expenses for Communication					
Electricity	2'940	34'425	112'740	68'820	Nkf
Total costs	**9'994'611**	**12'563'463**	**13'500'259**	**12'100'587**	**Nkf**

9.3. Transition Specification

In the follwing the transition of the model are presented. Few transitions, such as the internal skip collection for the decentralised composting scenario, are not illustrated. The relevant information for these transitions is simply to be taken from the descriptions in the report.

9.3.1. Administration

***Table 33**: In- and output specification for the transition of administration.*

Material	Variabel	Quantity	Unit
Input			
Mixed waste	X00	44'364	t
Output			
Mixed waste	Y00	44'364	t

```
Specification:

Output = Input
Y00=X00
Administration
BZ20=1
```

***Table 34:** Cost allocation for the transition of administration.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ20	248	Nkf/BZ20
Exp. auxiliary materials	BZ20	23'067	Nkf/BZ20
Salaries	BZ20	98'046	Nkf/BZ20
Exp. for comm. & elect.	BZ20	2'940	Nkf/BZ20
Total costs	BZ20	124'301	Nkf/BZ20
Income from service	BZ20	12'282'145	Nkf/BZ20
Total income	BZ20	12'282'145	Nkf/BZ20

9.3.2. Street Sweeping

***Table 35:** In- and output specification for the transition of street sweeping.*

Material	Variabel	Quantity	Unit
Input			
Rejected waste	X00	17'745	t
Output			
Rejected waste	Y00	17'745	t

```
Specification:

Output = Input
Y00=X00
Number of wheelbarrows and workers
BZ11=407
```

***Table 36:** Cost allocation for the transition of street sweeping.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ11	27	Nkf/BZ11
Exp. auxiliary materials	BZ11	73	Nkf/BZ11
Salaries	BZ11	750	Nkf/BZ11
Machinery / Vehicles	BZ11	94	Nkf/BZ11
Total costs	BZ11	945	Nkf/BZ11

9.3.3. Tranfer Point

Table 37: *In- and output specification for the transition of transfer point.*

Material	Variabel	Quantity	Unit
Input			
Rejected waste	X01	5'124	t
Rejected waste	X02	17'745	t
Compostable waste	X00	9'516	t
Output			
Rejected waste	Y01	22'896	t
Compostable waste	Y00	9'516	t

```
Specification:

transfer station
Y00=X00
Y01=X01+X02
Number of skip containers
BZ10=268
```

Table 38: *Cost allocation for the transition of transfer point.*

Cost type name	Cost Driver	Prop. Costs	Unit
Machinery / Vehicles	BZ10	2'275	Nkf/BZ10
Total costs	BZ10	2'275	Nkf/BZ10

9.3.4. Skip Collection

Table 39: *In- and output specification for the transition of skip collection.*

Material	Variabel	Quantity	Unit
Input			
Fuel & lubricants	X06	81'332	l
Rejected waste	X00	22'869	t
Compostable waste	X05	9'516	t
Output			
Rejected waste	Y02	22'869	t
Compostable waste	Y03	9'516	t

Table 40*: Parameter definition for the transition of skip collection.*

Name of parameter	Variabel	Quantity	Unit
Transport distance of loader per trip	C00	16	km
Velocity of truck (avarage)	C01	16	km/h
Working hours per day	C02	8	h
Volume capacity of loader	C03	7	m3
Density of waste in loader	C04	380	kg/m3
Fuel consumption of loader	C05	0.32	l/km
Attendance of loader	C06	90	%
Working days per year	N00	243	
Density of fuel (diesel)	N01	0.84	kg/l

```
Specification:

Output = input
Y02=X00
Y03=X05
Fuel consumption per year for all skip loaders
Fuel consumption = transport distance * specif. fuel con-
sumption
No. loaders * No. trips per year * density of diesel fuel
```

```
(Kubrom, 2004)
X06=C00*C05*BZ7*NoTripsY*N01 +
0.3*(C00*C05*BZ7*NoTripsY*N01)
1. Amount of waste per skip loader
Amount of waste = Density of waste * Volume of skip /
1000  (Kubrom, 2004)
AmSkl=C04*C03/1000
2. Time needed for one trip
Time = distance / velocity of loader (Kubrom, 2004, own
assumption)
Trspzeit=C00/C01
Number of trips per loader and day
Number = 1 / time * working hours per day (Kubrom, 2004)
NoTripsT=1/Trspzeit*C02
Number of trips per yaer
Number = No. trips * working days per year
NoTripsY=NoTripsT*N00
Max. load per loader and yaer
Load = No. trips per year * Amount of waste * attendance
of loader
Lmax=NoTripsY*AmSkl*C06
Number of skip loaders = Integer value of (total waste
transported per year / max. load )
Z00g=INT((X00+X05)/Lmax)
If capacity is overloaded, add one more loader!
BZ7=INT(IF(=((X00+X05)/Lmax,Z00g),Z00g,Z00g+1)/1000)
```

Table 41: *Cost allocation for the transition of skip collection.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ7	55	Nkf/BZ7
Exp. auxiliary materials	BZ7	77'000	Nkf/BZ7
Exp. ext. service	BZ7	15'703	Nkf/BZ7
Salaries	BZ7	40'920	Nkf/BZ7
Machinery / Vehicles	BZ7	351'106	Nkf/BZ7
Insurance of assets	BZ7	1'291	Nkf/BZ7
Total costs	BZ7	486'075	Nkf/BZ7

9.3.5. Landfill

Table 42: *In- and output specification for the transition of landfill.*

Material	Variabel	Quantity	Unit
Input			
Fuel & lubricants	X04	23'827	l
Rejected waste	X01	22'869	t
Rejected waste	X05	4'166	t
Compostable waste	X00	9'515	t
Compostable waste	X06	7'786	t
Output			
Landfill material	Y01	4'200	t
Gas & water losses	Y02	8'651	t

Table 43: *Parameter definition for the transition of landfill.*

Name of parameter	Variabel	Quantity	Unit
Working hours per day	C02	8	h
Fuel consumption of loader	C05	12	l/h
Workload	C06	0.75	
Working days per year	N00	243	
Density of fuel (diesel)	N01	0.84	kg/l

```
Specification:

Landfill generates different outputs:
1. Generation of emissions due to degradation of organic
waste
Emissions (fermentation & H20 losses) = 50% of composta-
ble waste
tranfer coefficient from Information on Composting and
Anaerobic Digestion, Orca 1992
Y02=0.5*(X00+X06)
One part is sold = known, fix value of around 4200 tons
(Drescher, 2003)
Y01=4200000
Fuel consumption per year for loader
Consumption =  hour per day*fuel consumption*No load-
ers*density of diesel fuel
X04=C06*C02*C05*BZ8*N00*N01 +
0.3*(C06*C02*C05*BZ8*N00*N01)
Number of Front-Loaders
BZ8=1
```

Table 44*: Cost allocation for the transition of landfill.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ8	83	Nkf/BZ8
Exp. auxiliary materials	BZ8	138'600	Nkf/BZ8
Exp. ext. service	BZ8	14'743	Nkf/BZ8
Salaries	BZ8	31'320	Nkf/BZ8
Machinery / Vehicles	BZ8	241'463	Nkf/BZ8
Insurance of assets	BZ8	1'291	Nkf/BZ8
Total costs	BZ8	427'499	Nkf/BZ8

9.3.6. Centralised Composting

Table 45: *In- and output specification for the transition of centralised composting.*

Material	Variabel	Quantity	Unit
Input			
Fuel & lubricants	X07	15'885	l
Rejected waste	X04	22'869	t
Rejected waste	X05	4'166	t
Compostable waste	X00	9'515	t
Compostable waste	X02	7'786	t
Water	X06	5'000	t
Output			
Rejected waste	Y01	27'062	t
Compostable waste	Y00	1'730	t
Compost	Y02	4'672	t
Gas & water losses	Y03	10'900	t

Table 46: *Parameter definition for the transition of centralised composting.*

Name of parameter	Variabel	Quantity	Unit
Working hours per day	C02	8	h
Fuel consumption loader	C05	12	l/h
Workload	C06	0.5	
Working days per year	N00	243	
Density of fuel (diesel)	N01	0.84	kg/l

```
Specification:

transition Centralised Composting plant
Sum of compostable waste
CompWTot=X00+X02
Sum of inorganic waste - no reduction
Y01=X04+X05
Generated compost
Assumption 90% of compostable waste can be separated from
waste stream
After decomposition 30 weight-% are available as compost
CompW=0.9*CompWTot
Compostable waste going to landfill
Y00=0.1*CompWtot
Out of 90% of compostable waste (CompW) emissions and
other product,
as well as compost is produced
30% is compost
70% are gas & water emissions and other products
Y02=0.3*CompW
Y03=0.7*CompW
Water consumption depending on number of centralised com-
posting plants
BZ30=1
X06=BZ30*5000000
Front loader
BZ8=1
Fuel consumption per year for loader
Consumption =  workload*spec. fuel consumption*working
hours per day*No loaders*density of diesel fuel
X07=C06*C02*C05*BZ8*N00*N01+0.3*(C06*C02*C05*BZ8*N00*N01)
```

Table 47: *Cost allocation for the transition of centralised composting.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ30	412'500	Nkf/BZ30
Exp. auxiliary materials	BZ30	15'000	Nkf/BZ30
Exp. ext. service	BZ30	51'000	Nkf/BZ30
Salaries	BZ30	1'117'500	Nkf/BZ30
Machinery / Vehicles	BZ30	603'281	Nkf/BZ30
Exp. for communication & electricity	BZ30	34'800	Nkf/BZ30
Other expenses	BZ30	126'000	Nkf/BZ30
Total costs	BZ30	2'360'081	Nkf/BZ30

9.3.7. Decentralised Composting

Table 48: *In- and output specification for the transition of decentralised composting.*

Material	Variabel	Quantity	Unit
Input			
Rejected waste	X01	5'124	t
Rejected waste	X04	4'192	t
Rejected waste	X05	17'745	t
Compostable waste	X00	9'516	t
Compostable waste	X03	7'785	t
Water	X02	6'000	t
Output			
Rejected waste	Y01	27'062	t
Compostable waste	Y02	1'730	t
Compost	Y00	4'671	t
Gas & water losses	Y03	11'900	t

Table 49: *Parameter definition for the transition of decentralised composting.*

Name of parameter	Variabel	Quantity	Unit
Organic waste coverage	C40	0.9	-
Ratio compost / organic waste	C41	0.3	-

```
Specification:

Total waste to be processed
WasteTot=X00+X01+X03+X04+X05
1. Separation/sorting:
Composable waste
CompWTot=X00+X03
Rejected waste - no reduction
Y01=X01+X04+X05
Only a fraction (C40) of the generated organic waste is
separated from the mixed waste
CompNet=C40*CompWTot
the rest is disposed of
Y02=(1-C40)*CompWtot
2. Composting process (simplified calculation):
Gas and water losses during degradation process
Y03=(1-C41)*CompNet
Compost produced - C41 represents ratio compost/organic
waste according to Rytz(2001)
Y00=C41*CompNet
Water consumption depending on number of "3 tons mixed
waste /day" centralised composting plants. Number depends
on amount of waste generated.
Total plant capacity per year = Plant capacity per day *
working days per year
Cap=3000*N00
Number of plants required = Total mixed waste that has to
be processed per year / Plant capacity per year
Number = Integer value of (total waste processed per year
/ plant capacity per year )
BZ31=INT((WasteTot)/Cap)
If capacity is overloaded, one more plant is added!
Y04=BZ31
BZ31=55
each plant consumes 100000 litre / year
X02=BZ31*100000
```

Table 50: *Cost allocation for the transition of decentralised composting.*

Cost type name	Cost Driver	Prop. Costs	Unit
Exp. raw material	BZ31	750	Nkf/BZ31
Exp. auxiliary materials	BZ31	15'000	Nkf/BZ31
Exp. ext. service	BZ31	3'000	Nkf/BZ31
Salaries	BZ31	112'500	Nkf/BZ31
Exp. for communication & electricity	BZ31	1'830	Nkf/BZ31
Other expenses	BZ31	4'500	Nkf/BZ31
Total costs	BZ31	137'580	Nkf/BZ31

9.4. Sankey-Diagrams

9.4.1. Centralised Composting

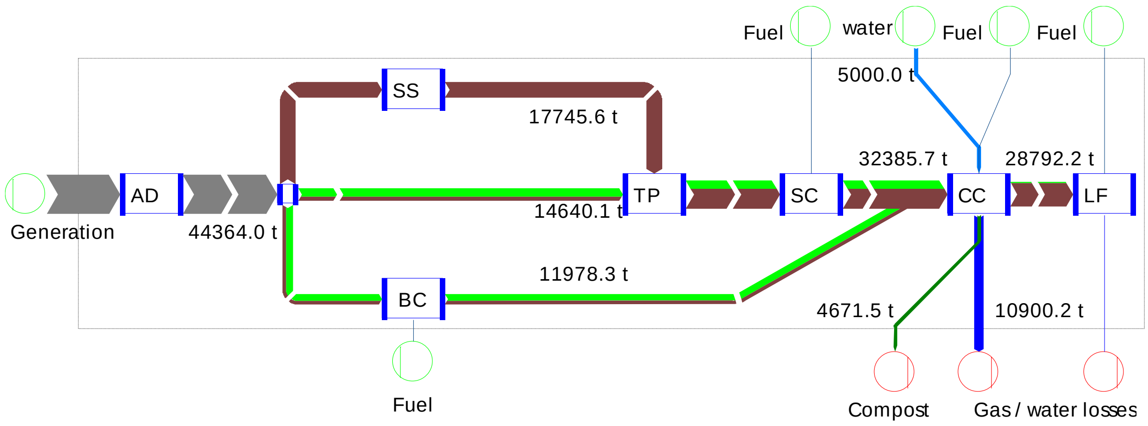

Figure 21: *Sankey-diagram for the centralised composting system.*

9.4.2. Decentralised Composting 1

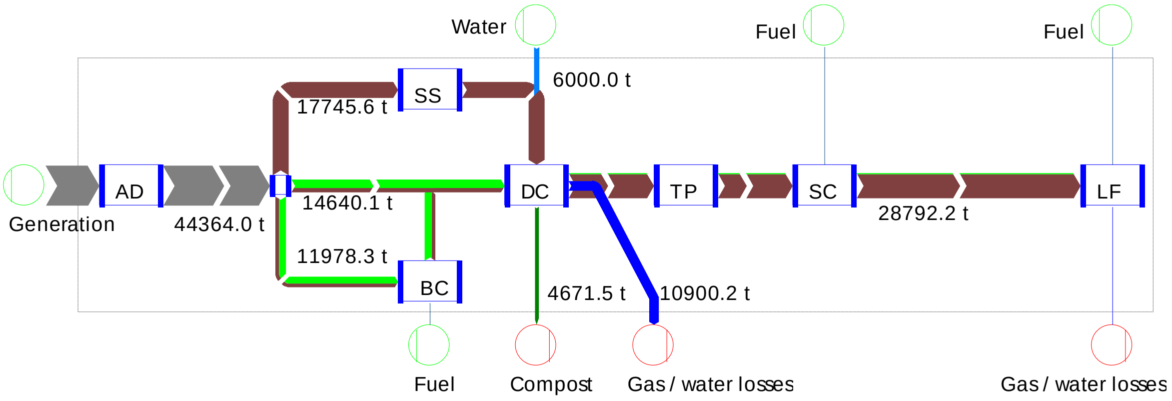

Figure 22: *Sankey-diagram for the decentralised composting system 1.*