Decentralised Composting - Assessment of Viability through Combined Material Flow Analysis and Cost Accounting

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SUMMARY: The approach described in this paper assists in visualising the existent solid waste management (SWM) system and estimate cost implications achieved by implementing composting units, seen from the municipality's viewpoint. The new approach combines the methods of material flow analysis and cost accounting. In a first step, the recent solid waste management of a city is assessed and visualised. Then, possible future SWM scenarios are developed, considering different composting options as treatment options for the biodegradable waste fraction. The approach provides information about waste flows, process costs and overall cost type structures of current and future SWM systems. In the presented case of Asmara, decentralised composting proofed to be favourable compared to centralised composting if applied for selected waste streams. Results show that a decentralised composting strategy significantly reduces transportation costs which partly compensate the investments and operation costs of the decentralised composting systems.

Decentralised Composting, Material Flow Analysis, Process Cost Analysis, Municipal Solid Waste

1 Introduction

Decentralised composting is one possible approach to treat and recover the biodegradable fraction of the solid waste stream in an urban system. Decentralised composting units on backyard, neighbourhood or community level significantly reduce the waste amount that otherwise needs further handling by the responsible entity. Furthermore, they also improve the hygienic condition in the neighbourhood, as they are often closely linked to an improved primary waste collection system. Such waste recycling close to the source of generation has a high potential to reduce costs of transport, as well as costs of the disposal facilities, by prolonging the landfill sites life span. The later facts have a particular relevance for low- and middle income countries in Asia, Africa and Latin America as urban waste streams contain 50 to 70 % of biodegradable waste (Bezama et al., 2006, Mrayyan et al., 2005; Henry et al., 2005; Dias et al., 1996) which is subject to rapid degradation causing environmental degradation and health risks in urban areas (Hardoy et al., 2001; Rajagopal, 1998).

In the past several municipalities tried to tackle the organic waste amount with large-scale and centralised composting projects. However, the experience from India shows that such projects are prone to failure, mostly due to limited revenues and high investment and operation costs (United Nations Development Programme, 1991). Failures can be attributed to inappropriate technologies for developing countries as well as the limited and underdeveloped market for the compost product. Recent initiatives, which again want to establish large-scale composting plants supported by anticipated revenues from the Clean Development Mechanism (CDM) still have to prove their sustainability (UNFCCC, 2006).

As a consequence of the past failures, since the 1990s, decentralised composting on neighbourhood level is considered as a more suitable solution for developing countries. Several community organisations and non-governmental organisations (NGO) initiated small-scale and medium scale composting schemes in cities. Decentralised composting has the potential to

- improve the precarious waste situation in communities as it often goes along with an improved primary waste collection,

- reduce the waste amount that needs further handling by the responsible entity (e.g. municipality),
- be manageable by residents or local entrepreneurs due to less complexity of technology,
- offer new employment opportunities to underprivileged people,
- be implemented step-by-step, as small units can be set up independently.

Furthermore, small-scale composting units have a positive influence on the total expenditures for urban solid waste management (SWM). For a municipal authority responsible for solid waste management recycling organic matter can reduce

- costs of transport,
- costs of the disposal facilities, by prolonging the sites life span and
- environmental impacts such as ground water pollution or greenhouse gas emissions from landfills.

Therefore, small-scale composting units have - despite their higher unit costs - a positive influence on the total expenditures for urban solid waste management (SWM). In addition to these direct financial savings, spillover effects such as economic benefits due to employment generation, poverty alleviation, less use of foreign exchange for fertilisers or imported machinery and an overall improved environmental management can also be taken into account. Specific data on such financial and economic cost savings are yet scarce although such essential information is needed for strategic planning and informed decision making by the municipal authorities.

The approach described in this paper assists in visualising the existent solid waste management system and estimate cost implications achieved by implementing composting units, seen from the municipality's viewpoint. Basis for such a study are interested municipalities and/or private contractors as partners with a good knowledge of their solid waste expenditures and the willingness to share the data.

2 Methodology

2.1 Approach

The new approach combines two well established analytical methods to evaluate the viability of decentralised composting within an urban solid waste management system: Material Flux Analysis (MFA) and cost accounting (CA). The MFA component visualises the waste flows and processes (e.g. waste generation, temporary storage, transportation, treatment or disposal) over a defined time period of a city's sold waste management (SWM) system. Based on the model of the existing SWM system, future treatment scenarios can be modelled and calculated. This approach allows the visualisation of changes in waste flows and costs induced by new processes. For instance, it is possible to compare scenarios considering decentralised vs. centralised composting. The CA component allocates fixed and variable costs of the system to the activities or processes defined in the MFA and calculates partial and total cost-revenue balances. 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.

Several computer based assessment tools are available, which focus either on environmental impacts or costs (McDougal et al., 2002 or Thorneloe, 2001). However, these programmes either hardly allow a detailed financial analysis of the system or provide default values from experiences in industrialised countries which do not reflect the situation in low- and middle-income countries. Therefore, this new approach tries to close the gap by providing a model which allows the adjustments of parameters to the situation prevailing in low- and middle income countries.

2.2 Material Flow Analysis

Material Flow Analysis is a systematic assessment of the flows of materials and resources within a defined system (Brunner and Rechenberger, 2004, and Daniels and Moore, 2002). It bases on the law of material conservation. MFA can be carried out for substances as well as goods. MFA for substances, often named substance flow analysis (SFA), is a method for investigating pathways of specific substances through anthropogenic and natural systems (Baccini and Brunner, 1991; Baccini and Bader, 1996a and 1996b; Voet, 1996). Most SFA studies are motivated by a specific environmental problem associated with the substance under study such as heavy metals (Bergbäck 1992; Jonsson, 2000 and Sörme, 2003) or nitrogen (Voet, 1996). The use of SFA helps to relate critical emissions of these substances to processes, products and material inputs in the system. Material flow analysis for goods, defined as “materials with a positive or negative economic value” (Brunner et al., 1998, p.5), is closely related to SFA (Baccini and Bader, 1996a and 1996b; Bringezu, 2000). Examples are studies, analysing the use of land, energy and non-renewable resources. MFA studies link the use of natural resources to consumer needs, economic structures or technological development (Müller, 1998; Redle, 1999; Faist et al., 2001; Hug and Baccini, 2002).

MFA is increasingly used for modelling material flows on regional or even global level (Hendriks, 2000). Waste management is a very important application for MFA. Numerous examples are given in Baccini and Bader (1996a), Brunner and Rechenberger (2004) and McDougal et al. (2002). Applications in developing countries are described in Binder et al. (2001) and Streicher-Porte (2005).

Figure 1 shows a generic visualisation of a typical urban SWM system with its processes and material flows: Waste is generated by households, collected directly (BC) or disposed of at temporary disposal points (TP). From there, it is collected and transported to either a treatment plant or the final disposal site (LF). Such presentations facilitate discussions and allow the allocation of costs to the processes occurring in the system.

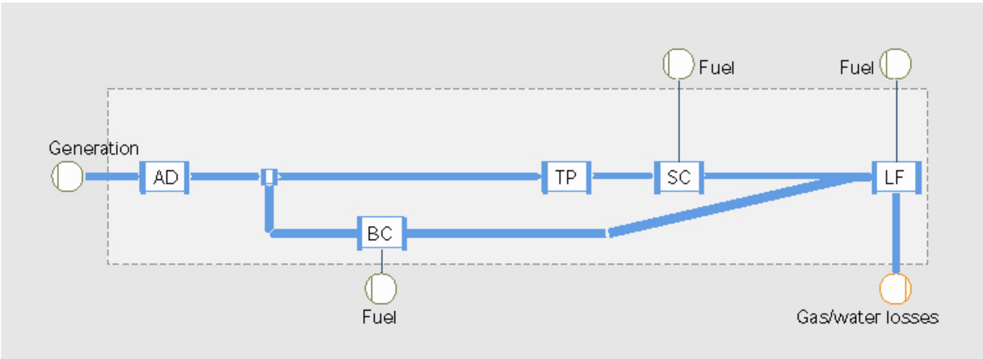

Figure 1 Defining system boundaries, processes and material flows of a solid waste management system (AD=Administration, BC=Block Collection, TP=Transfer Points, SC=Skip Collection, LF=Landfill)

2.3 Cost accounting in combination with MFA

Cost accounting is the process of tracking, recording and analysing costs associated with the products or activities of an organisation to support decision making and to improve costs and cash flows (wikipedia Free Encyclopedia). All costs which are associated to products or activities are classified and calculated (Jewell, 2000). Traditional cost accounting differentiates between cost types (what costs?), cost centres (where?) and cost units (for what purpose?). These entities have to be defined for each specific case depending on the questions to be answered by cost analysis. This definition marks a crucial step in analysis as it determines the scope and the level of detail of the analysis.

When applied in combination with MFA, the definition of cost types, centres and units in cost calculation has to be consistent – to some degree – with the definition of system boundaries, processes and material flows in MFA (see Fig. 1). In the methodological framework proposed in this paper, we suggest a high degree of consistency. This means that cost centres in the cost calculation are identical with processes in MFA. The cost unit in the system is the amount of waste collected (input flow from generation in Fig. 1). Cost types, however, represent additional information that is not part of the MFA system (i.e. labour, electricity, depreciation, administration costs). The cost types shown in Table 3 reflect the main types observed in waste management in developing countries. A further break down is not appropriate as experience shows that such detailed financial data in municipalities are not available for the solid waste management sector in municipalities in low- and middle income countries.

Cost types are attributed to the cost centres (MFA processes) and allocated to the cost unit (amount of waste collected) according to the amount of material turnover in each cost centre (mass proportional cost allocation). This information is of particular interest as we want to analyse the interdependency of several subsequent or

interrelated processes. Therefore, it also allows determining the effect of composting activities on mass flows and costs on the whole SWM system.
In case a mass proportional cost allocation does not fully reflect the cost drivers in the system, the model can be extended. Costs for transportation, for example, depend highly on the number of trucks and related costs (e.g. maintenance and depreciation). The number of trucks, however, is not linearly dependent on the amount of collected waste. Thus, the model calculates the number of trucks as an additional parameter based on step functions to better capture the (non-linear) relation between amount of collected waste and number of trucks. In this case the number of truck represents the cost driver. Such extensions are commonly known in activity based costing, a special type of cost accounting focussing on the identification and representation of cost drivers. Yet, we refrain from classifying the cost accounting scheme used in our model as activity based costing for two reasons. Firstly, traditional cost accounting is more commonly known and sufficient to understand the methodological framework. Secondly, activity based costing was primarily developed to better cope with planning and controlling of fixed costs. In our study, however, we do not have this focus but analyse all cost types related to waste management.

2.4 Tools

The MFA model assumes that processes are linked by material flows. Processes either change the materials flowing though or just pass them on to another process. Such transformation or transport activities cause costs which can be again classified by cost types for each process. Furthermore, the material flows also influence the process costs as the mass flows determine the number of trucks or number of composting plants necessary for providing sufficient service. Materials or energy also can have monetary attributes (costs or revenues) which can also be balanced in such a system. For example, compost as an output has a price attribute which, together with the calculated output flow, finally determines the revenues obtained from compost sales. The MFA tool umberto® was used to facilitate the modelling and data calculation for that approach as it also allows the integration of financial data. Additionally, some cost calculations had to be done beforehand and afterwards with a spreadsheet calculation (i.e. Excel). Particularly the data collection was prepared and facilitated by spreadsheet tables.

2.5 Parameter Definition

The definition of the processes within the software tool required special attention as the appropriate balance between simplification and accuracy of the model has to be found. Therefore, each process is defined by different parameters which determine either physical changes of the material flow or determine cost effects within the process. Table 1 exemplifies the type and use of parameters for a transport process as established in the case study of Asmara. In this process material remains unchanged during transport and therefore only one material specific parameter is defined. The parameters fully describe the transport process including distances, average velocities, fuel consumption and working hours. The parameters are both relevant for calculation of the required number of vehicles and the costs (including personnel costs). Working with parameters allows the flexible adjustment of the model to the prevailing situation in many cities or regions.

Table 1 Process and net-parameters for the process “block collection”

Parameter	**Variable**	**Default Value**	**Unit**
Transport distance of vehicle per trip (return)	C00	24	km
Velocity of vehicle (average)	C01	9	km/h
Working hours per day	C02	8	h
Volume capacity of vehicle	C03	13	m^3
Density of waste in vehicle	C04	130	kg/ m^3
Fuel consumption of vehicle	C05	0.32	l/km
Attendance of vehicle	C06	65	%
Working days per year	N00	243	
Density of fuel (diesel)	N01	840	kg/m^3

The definition and later variation of parameters allows determining cost implications or sensitivities for future scenarios. For instance, the parameter “transport distance” can be varied which would influence the time required for transport and thus the amount of vehicles, necessary for transporting a fixed amount of waste. The number of vehicles subsequently influences the transportation costs such as salaries, depreciation or fuel of the overall SWM system. For each of the processes involved in solid waste management such parameters are designed.

2.6 Reality Check with Case Studies

The approach was tested in three cities in development countries which represent different city types regarding their population and organisational settings. The aim was to test the applicability of the approach under different conditions, such as number of population, technological standing, and data availability and accuracy (Table 2).

Table 2 Overview of three case studies

City	Country	Population	Scope of study	Characteristics
Bouargoub	Tunisia	~10 000	entire town	Rural town with simple management structures, technical and financial data available or easy to collect.
Asmara	Eritrea	~300 000	entire town	Capital of Eritrea, centralised organisational structures, technical and financial data available from responsible units or possible to collect.
Dhaka	Bangladesh	~6 500 000	Dhanmondi Ward	Capital of Bangladesh, densely populated, complex organisational structures, data available only as accumulated figures in literature or through own investigations, difficult access to municipal data

For each case a baseline scenario was developed by assessing the current situation regarding waste flows, processes involved and financial implications. In a second step, scenarios were developed by consulting decision makers and local experts about additional case specific information. New scenarios of interest considered an improved landfill management and/ or centralised and decentralised composting facilities as part of the SWM system of the respective city.

Due to the prevailing governance situation, each of the cases required individual strategies and methodologies to assess the data and develop relevant scenarios. However, some general activities could be defined allowing the modelling of the baseline scenario and future scenarios:

1. Identify local stakeholder with scientific technical background in order to facilitate the data collection and analysis.
2. Contact and discuss with responsible SWM unit within the municipality the scope of study and define the system boundary, processes and waste flows to be assessed.
3. Identify and review existing reports, technical monitoring documents and financial accounts.
4. Draw a first MFA model as baseline scenario (processes and material flows) and insert the data available. The MFA will immediately reveal the gaps or inconsistency of data.
5. Collect missing data by own investigations in cooperation with responsible unit – this is especially relevant for the costs and revenues.
6. Amend and detail the baseline scenario regarding the material flows. Allocate costs and revenues to the corresponding processes and material flows.
7. Develop possible and relevant future scenarios together with the responsible units and discuss the technical and financial implications.
8. Transfer the scenarios into the MFA system, adjust the material flows and allocate the new cost and revenues to the new established system.
9. Present results to all involved stakeholders and discuss the consequences of the findings.

3 Results and Discussion

The case study of Asmara in Eritrea exemplifies the functionality of the approach described above and reveals interesting results. This chapter gives information about the SWM system in Asmara before describing the outcomes of the study.

3.1 Basic Information about the SWM System of Asmara

Asmara is both the capital of Eritrea and administrative centre of the Maakel Region, which is one of six administrative regions. Asmara is located on a highland plateau which is one of the most important agricultural areas of Eritrea. However, according to Stillhardt et al. (2002) the soils are poor in nutrients and organic matter and farmers have a high demand for affordable organic and inorganic fertilisers. Compost retrieved from municipal solid waste is regarded as a valuable fertiliser for peri-urban agriculture. Thus, the Administration of Maakel region was interested to strengthen the already existing link between urban waste management and the surrounding agricultural activities (Drescher and Tesfay, 2005). The Sanitation Unit (SU) of the municipality was therefore interested in a cooperation and analysis of the existing solid waste management system and options for an improved reuse of organic matter from waste in Asmara. For Asmara, four scenarios - including the current situation - were developed:

- Current situation (Baseline)
- Centralised composting (CC): with one large composting plant at the landfill (180 tons per day)
- Decentralised composting 1 (DC 1): with 60 small composting sites (3 tons per day) throughout the city treating all generated waste
- Decentralised composting 2 (DC 2): with 36 small composting sites (3 ton per day) throughout the city treating selected waste streams which are high in biodegradable waste

In this paper the results and conclusions from two out of four scenarios are presented: The current situation (Baseline) and the decentralised composting 2 (DC2). The complete study is documented by Kubrom et al. (2004) and Müller (2006).

In four weeks time, the project team together with the sanitation unit determined the system boundary, relevant processes and material flows. They collected all relevant data to define the crucial calculation parameters for all processes and developed the baseline. With this information and further assumptions regarding the specification of non-existent facilities such as the centralised composting plant or the decentralised composting plants a calculation of the material flows and implicated costs was possible.

Asmara has nearly 400 000 inhabitants which generated 53 332 tons of mixed municipal waste in 2004. (Kubrom et al., 2004). Assuming a collection efficiency of 80 %, the Sanitation Unit (SU) collects 44 364 tons of waste per year with container and compactor trucks. The waste is transported to a landfill located 6 km from the city. (20 % of the waste remains in open space or drains and is collected during an annual cleanup campaign organised by the SU. This waste fraction was not considered in the following calculation). According to a study of Habtetsion et al. about 52 % of the solid waste is biodegradable and suitable for composting. (Habtetsion, 1999).

3.2 Material Flows and Processes in Asmara

The following two figures show exemplary outputs of a material flow analysis as Sankey display.

For the baseline scenario (Figure 2) the project team defined the relevant processes *Administration* (AD), *Skip Collection* (SC), *Block Collection* (BC), *Street Sweeping* (SS), *Transfer Points (Containers)* (TP) and *Landfill* (LF). Input material flows are defined as: *mixed waste* (grey) and *fuel*. Material flows inside the system are *rejects* (dark grey) and *biodegradable waste* (light grey). Output materials are defined as *gas/water losses* and *landfill material* sold to farmers. The weight of the arrows represents the amount of waste flowing through the system. The processes BC and SC are designed to calculate the number of vehicles necessary for the collection and transport of the total waste amount as described in chapter 2.5.

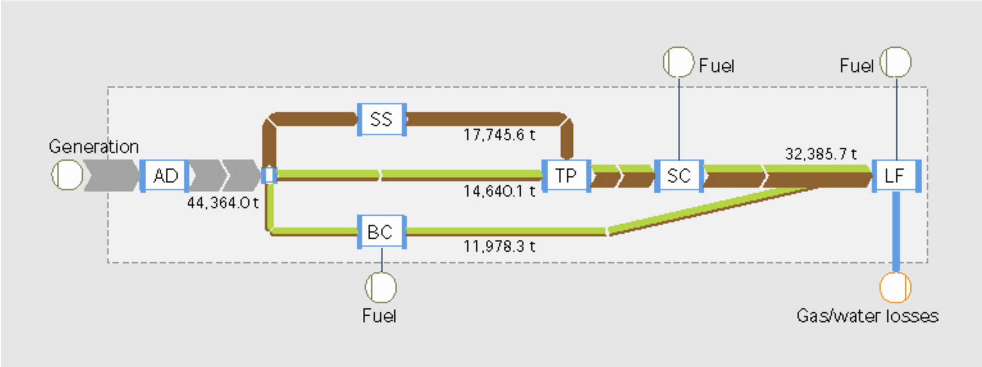

Figure 2 Material flow analysis for the current SWM situation in Asmara (Baseline)

Figure 2 shows that *street sweeping* is an important process in the SWM system of Asmara which was underestimated so far. Almost 40 % (17 745 tons) of the total annual waste amount is collected by the street sweeping team (407 street sweepers). The remaining waste is almost equally collected by compactor trucks in the BC process (27 %) and by skip loaders in the SC process (container system, 33 %). An analysis of the separated waste flows revealed that waste coming from street sweeping is not suitable for composting due to a high content of inorganic material and therefore should be directly transferred to the landfill site. This information could already be considered in the future scenarios which included composting as a treatment option.

Figure 3 shows the result of such a scenario considering decentralised composting as a treatment option for the organic fraction of selected waste sources. The MFA-system in Figure 3 appears more complex as new processes and material flows had to be defined. Additionally to the previous scenarios, *Decentralised Composting* (DC) is defined as an additional process in the system. Water and Compost are new input and output flows respectively. Likewise the transportation processes, the process DC calculates the required number of small scale composting plants according to the waste input to the process and the defined capacity of the composting plant. The calculation results in 36 decentralised composting plants with a capacity of three tons of mixed incoming waste per day and plant throughout the city. This number is sufficient for treating 26 618 tons of waste delivered by vehicles or directly from households.

Based on the findings shown in Figure 2, the new scenario depicted in Figure 3 considers waste from street sweeping as rejects and diverts it directly to containers determined for land filling (dark grey). Therefore, only waste from households, markets and businesses is collected and treated in the provided composting facilities (DC) (light grey).

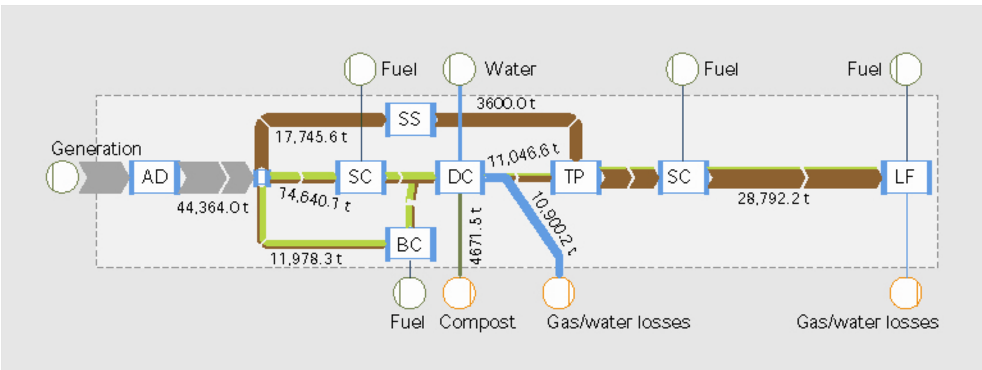

Figure 3 Material flow analysis for a possible future SWM system in Asmara considering decentralised composting as treatment option for organic waste (DC2)

Surveying the changes in waste flows the model reveals that 15 572 tons less waste has to be transported to the landfill site, as it is treated inside the city boundaries. This is equivalent to a waste reduction potential of 35 % or about 5 000 truck-trips to the landfill site. Furthermore, the scenario reveals that about 4 670 tons of compost is produced, which would be absorbed by the agricultural sector immediately as it covers about 80 % of the current demand for organic matter currently mined at the landfill site (Ogbazghi et al., 2005).

Generally, the development of these models is a suitable means for communication and planning. The concept of material flows and processes is easily understood by practitioners and decision makers. Defining and drawing these systems already improved the communication of the project team and focused the discussion on neuralgic processes in the system. Much effort was necessary to define and specify the transportation processes. They turned out be the most determining factor with regard to cost implications. Furthermore, transportation is a limiting factor for the efficiency of the SWM system in Asmara. The results revealed potentials to improve waste collection and transport efficiency through decentralised composting which also significantly influences cost structures. This will be further specified in the following chapter.

3.3 Financial Analysis

As reported by the municipal authorities, the annual budget of the solid waste management department amounts to about 12.3 million Nakfa (US$ 819,000), which cover the costs of solid waste collection and latrine emptying services. The major part - about 10 million Nakfa (US$ 667 000) - is currently spent for solid waste management. The various cost items of the solid waste management system (e.g. salaries, maintenance, fuel cost, depreciation etc.) were calculated using the data provided by the Administration of the Maakel Region and further investigations of the research team. The data was allocated to the processes defined in the MFA model and material flows and costs could be calculated simultaneously. Total annual costs and cost distribution among the processes are graphically illustrated in Figure 4. For all scenarios the street sweeping process remains unchanged.

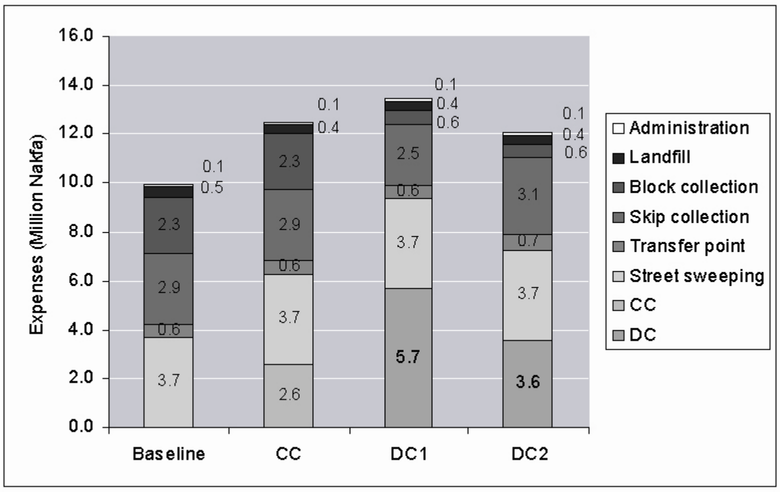

Figure 4 Cost distribution according to processes

For the existing baseline situation (first column in Figure 3), the total annual costs (fixed and variable costs) of solid waste management are about 10 million Nakfa, whereof 57% are related to waste collection and transport (BC and SC). Figure 4 also includes total costs and process cost distribution of all modelled alternative scenarios. The “centralised composting” scenario with one large composting plant at the landfill (180 tons per day), reveals an annual cost increase of approx. 2.6 million Nakfa. Except a marginal reduction of costs for landfill management all costs remain the same as in the baseline.

The “decentralised composting 2” scenario (DC2), as depicted in Figure 3, assumes that only waste from households and markets is treated in decentralised composting plants. Though the decentralised composting schemes cause a significant cost increase for treatment (3.6 million Nafka) and is therefore more expensive than the centralised composting plant, the total costs of the SWM system are lower than in the “centralised composting” scenario (CC). This effect can be mainly attributed to significantly reduced costs for transportation. For example, the costs for block collection decline from 2.3 million Nakfa to 0.6 million Nakfa, as transportation distances are massively reduced. This already indicates that decentralised composting has its advantages within a solid waste management system when implemented for selected solid waste streams. Especially, collection vehicles which are not suitable for long distance travelling can be used more efficiently if operated only within the city boundaries.
In general the distance between the place of waste collection and waste disposal is a crucial factor for the viability of decentralised composting. For the case of Asmara, an increase of transport distance from 6 km to 17 km already leads to a significant financial advantage for a decentralised approach. (Müller, 2006) As in many urban areas of developing countries the landfills are as far as 40 km away from the city centre and transportation is limited, decentralised treatment option carry a great potential for improved transport efficiencies.

Table 3 shows the results of the cost calculation according to cost types. While the process cost calculation allows an analysis of the occurrence of costs, the calculation of cost types provides additional information about the causes of cost increase or decrease. Table 3 clearly shows that the main cost types of the SWM of Asmara are salaries and depreciation of machinery and vehicles. They constitute 83 % of the total costs in the baseline and 84 % of the total costs in the DC1 scenario. The main cost driver in the decentralised composting scenarios is the required staff, while costs for depreciation can be reduced. Based on the baseline (4.6 Mio Nakfa) the salaries increase by 21% in the CC scenario and by 41% in the DC2 scenario. This strong increase of cost can only be partly compensated by achieved cost reduction for machinery or fuel. The lower depreciation costs of DC1 and DC2 can be attributed to the lower machinery investments for the composting facility and a possible reduction of vehicles. This effect corresponds with the reduced fuel costs (-42 %) for DC1 and DC2. In reality, of course, the number of transportation vehicles remains the same and cost savings are limited. However, the freed capacities can contribute to a significant increase of the overall SWM efficiency.
The significant increase in costs for auxiliary materials and electricity (DC1 and DC2) must be attributed to a multiplying effect. Costs for single decentralised composting plants are available from existing case studies which provide detailed cost calculations considering also auxiliary materials and electricity. Due to the high numbers of plants required even comparatively low costs have a significant effect on cost allocation.

Table 3 Cost distribution according to cost types (Nakfa)

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

Additional revenues are only achieved through compost sales. Assuming a price of 25 Nakfa per tonne, which is a conservative estimate, the revenues from compost sale range around 117 000 Nakfa. Compared to the total revenues from taxes and fees it is less than 1 %. Furthermore, the revenues do not cover the additional costs for the newly introduced composting activities.

4 Conclusions

Considering the outcomes of the presented case and also results of the other two mentioned case studies it is possible to identify common aspects and to draw generalised conclusions for the approach. For a comprehensive conclusion, two viewpoints have to be considered: Firstly, the applicability of the MFA-CA approach to assess alternative integrated solid waste management systems and secondly, the general lessons learned about the viability of decentralised composting in low- and middle-income countries.

4.1 Is the MFA-CA approach suitable?

The introduction of the approach of material flows and processes to stakeholders requires some time, but is understood by most of involved SWM officers and decision makers. The MFA allows municipal decision makers a view from a new angle on their waste management system. The thorough development and discussion of a baseline scenario facilitates further discussion on how to change or improve an existing SWM system.
The financial analysis is the most difficult part of the study, as almost all SWM units in low- and middle income countries work on basis of global budgets allocated to SWM. Officers are not used to allocate costs to defined processes and calculate unit costs. Therefore, external assistance for modelling and calculation was crucial in all cases. This means that the MFA-CA approach can hardly be followed by municipal officers in their day-to-day work and therefore remains a planning instrument for specialists. However, involved stakeholders have shown great interest and confirmed the usefulness of such a planning tool.
The MFA-CA approach requires the cooperation of the responsible units within a municipality, as especially reliable financial data can only retrieved from their files. Such cooperation can only base on transparency and trust of all parties, which is not given in some cities in low- and middle income countries or in cases where only a part of a city should be assessed.
The limitation of the approach and the model was revealed in the case of Bouargoub in Tunisia. The model immanent calculations in step functions might cause too high costs for small SWM systems where only two or three vehicles are in operation. If the amount of waste just exceeds the capacity of a composting plant or transportation vehicle it will calculate another plant or vehicle leading to significant cost increases. This effect might distort the future scenario. Therefore special attention must be given to threshold values in the material flows in small SWM systems.

4.2 Is decentralised composting a viable option?

The MFA- approach allowed the assessment of hypothesises regarding the viability of decentralised composting in low- and middle income countries. The analysis of the cost structure allows a differentiated discussion on the advantages and disadvantages of decentralised composting. Although operation of decentralised composting may be more expensive than centralised systems, the model reveals that, compared to a centralised plant, transport costs are reduced in decentralised composting. In the case of Asmara, 1.7 million Nakfa can be saved in transport costs as shown in Figure 4 (fourth column). Half of the additional costs, which would be necessary to implement and operate decentralised composting schemes, can thus be compensated by costs savings in transport and increased revenues through the sale of compost. This compensation would not be as significant with a centralised composting plant, as its transport costs remain unchanged. Furthermore, decentralised composting eases the operational and financial burden from the weakest link – transport – in the solid waste management chain. Allocation of capital for waste collection trucks, their operation and maintenance (fuel, spare parts) are a great challenge for many authorities in cities of low and middle income countries. Additionally, the lack of available land for final disposal within city reach is also of great municipal concern. The problem of limited transport capacity becomes even more acute with new landfill sites being constructed further away from the city centre. A possible extension of the landfill lifespan is achievable for both, the centralised and decentralised composting scenario. In the case of Asmara the life span could be extended by 20 % assuming a live span of 20 years. In both centralised and decentralised composting scenarios, improved solid waste management systems incur increasing annual costs. However, the question of how to allocate investments most efficiently remains to be discussed.

The results of the presented study suggest a reallocation of necessary new investments to decentralised composting schemes so as to use existing capacities more efficiently. Instead of just investing in new transport equipment and landfill extension, the investment can partly be channelled towards decentralised composting schemes. In the case of Asmara, decentralised composting would result in freeing existing truck fleet capacity, as only 64% of the initial waste volume has to be transported. The remaining capacity can be used to extend the SWM service to other areas, thus increasing system efficiency. The described approach not only allows predicting the financial outcomes of potential changes in the solid waste management system, but also contributes to enhancing decision-making. To conduct a reality check, Sandec has submitted the results obtained to the Eritrean and Tunisian authorities involved. A follow up is planned to deal with further questions arising from the current results and future plans of the stakeholders involved.

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References

Ayres, R.U. and Ayres, L. (1998/99): Accounting for Resources, I & II, Edward Elgar, London.

Baccini, P. and Bader, H.-P. (1996a): Regionaler Stoffhaushalt: Erfassung, Bewertung und Steuerung. Heidelberg Berlin Oxford, Spektrum Akademischer Verlag.

Baccini, P. and Brunner, P.H. (1991), Metabolism of the Anthroposphere. Berlin Heidelberg, Springer Verlag.

Bader H.-P. und Baccini P. (1996b): System-Modelle und Simulations-Programme im Umweltmanagement - Eine kritische Analyse zum Stand der Technik. GAIA, 5 (6): 263-275.

Bergbäck, B. (1992): Emerging landscape of heavy metals imission in Sweden. Disseration . Linköping Studies in Arts and Science.

Bezama, A., Aguayo, P., Konrad, O., Navia, R., Lorber, K.E., 2006. Investigations on mechanical biological treatment of waste in South America: Towards more sustainable MSW management strategies. Waste Management (in press).

Binder, C., Bader, H.-P. Scheidegger, R. and Baccini, P. (2001): Dynamic models for managing durables using a stratified approach: the case of Tunja, Colombia. Ecological Economics 38, 191-207.

Bringezu, S. (2000): Ressourcennutzung in Wirtschaftsräumen: Stoffstromanalysen für eine nachhaltige Raumentwicklung. Berlin ; Heidelberg ; ... Springer.

Brunner P.H., Rechenberger H., 2004. Practical Handbook of Material Flow Analysis, CRC Press LLC

Brunner, P.H. (Coordinator), Baccini, P., Deistler, M., Haes, U. de, Lohm, U., Vijversberg, A.J. (1998): Material Accounting as a Tool for Decision Making in Environmental Policy (Mac TEmPo). Summary Report of a EC Environmental Research Programme. Research Area III – Economic and Social Aspects of the Environment. Vienna University of Technology. Institute for Water Quality and Waste Management.

Daniels, P.L. and Moore, S. (2002): Approaches for quantifying the metabolism of physical economies: a comparative survey. Journal of Industrial Ecology, 6: 69-93.

Dias, L.F., Savage, G.M., Eggerth, L.L., Golueke, C.G., 1996. Solid Waste Management for Economically Developing Countries. International Solid Waste Association, Copenhagen.

Drescher, S. and Tesfay, A., 2005. Benefits and Risks of the Use of Organic Matter from the Asmara Landfill in Agriculture. Eawag/ Sandec, Dübendorf.

Faist, M., Kytzia, S. and Baccini, P. (2001): The impact of household food consumption on resource and energy management. International Journal of Environment and Pollution, 15 (2): 183-199.

Habtetsion, S., Ghirmay B., et al., 1999. The potentials of energy recovery from municipal solid waste and other sound practices in solid waste management. Asmara.

Hardoy, J.E., Mitlin, D., Satterthwaite, D., 2001. Environmental Problems in an Urbanizing World. Finding Solutions for Cities in Africa, Asia and Latin America. Earthscan Publications Ltd, London.

Heijungs, R. (1997): Economic Drama and the Environmental Stage: formal derivation of algorithmic tools for environmental analysis and decision-support from a unified epistemological principle. Soziale Wissenschaften. Leiden, Reiksuniversiteit.

Hendriks C., Obernosterer R., Müller D., Kytzia S., Baccini P. and P. Brunner, Material Flow Analysis (MFA) - a tool for regional environmental and resource management. Case studies on the City of Vienna and the Swiss Lowlands. Local Environment. Volume 5, No. 3, 2000, pp. 311-328.

Henry, R.K., Yongsheng Z., Jun, D., 2006. Municipal solid waste management challenges in developing countries - Kenyan case study. Waste Management 26, 92-100.

Hug F. and Baccini P. (2002): Physiological Interactions Between Highland and Lowland Regions in the Context of Long-Term Resource Management. Mountain Research and Development, 22 (2): 168-176

Jewell, B.R., 2000. An Integrated Approach to Business Studies. 4th Edition, Harlow.

Jonsson, A. (2000): The trace of metals: use emissions and sediment load of urban heavy metals. Dissertation. Linköping Studies in Arts and Science, 221.

Kubrom, T., Mehari, S. et al., 2004. Economic Valuation of Decentralized Composting, Case Study Asmara, Eritrea. University of Asmara, College of Agriculture, Asmara.

McDougal, F., white, P., Franke, M., Hindle, P., 2001. Integrated solid waste management: A Life-Cycle Inventory, Second Edition.

Mrayyan, B., Hamdi, M.R., 2006. Management approaches to integrated solid waste in industrialized zones in Jordan: A case of Zarqa City. Waste Management 26, 195-205.

Müller, C., 2006. Decentralised Composting in Developing Countries, Financial and Technical Evaluation in the Case of Asmara City. Diplomathesis, Sandec/ Eawag, Dübendorf.

Müller, D. (1998): Modellierung, Simulation und Bewertung des regionalen Holzhaushaltes. Untersuchung der Wald- und Holzwirtschaft in einer nachhaltigen Regionalentwicklung. Departement Bau, Umwelt und Geomatik. Zürich, ETHZ.

Rajagopal, K., 1998. India's Environment Pollution and Protection. Report No 97ED57, Central Research Institute of Electric Power Industry (CRIEPI, Japan), Tata Energy Research Institute (TERI), New Delhi.

Redle, M. (1999): Kies- und Energiehaushalt urbaner Regionen in Abhängigkeit der Siedlungsentwicklung. Umweltnaturwissenschaften. Zürich, ETHZ.

Sörme, L. (2003): Urban heavy metals stocks and flows. Disseration . Linköping Studies in Arts and Science, 76.

Stillhardt, B.,Herweg, K., Hurni, H., 2002. Long-term Monitoring of Soil Erosion and Soil and Water Conservation in Afdeyu, Eritrea (1984-1998),Centre for Development and Environment, Berne.

Streicher-Porte M., Widmer R., Jainc A., Bader H.-P., Scheidegger R. and S. Kytzia, Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi. Environmental Impact Assessment Review 25 (2005), pp. 472– 491.

Thorneloe, S.A., Weitz, K.A., Nishtala, S.R. 2001. U.S. Case studies using municipal solid waste decision support tool. Eighth International Waste Management and Landfill Symposium, October 1-5, 2001, Cagliari.

United Nations Development Programme, World Bank, Regional Water and Sanitation Group for South Asia, 1991. Indian experience on composting as means of resource recovery, in:Proceedings of the UNDP/WB Water Supply and Sanitation Program Workshop on Waste Management Policies, Singapore 1-5 July 1991.

United Nations Framework Convention on Climate Change, 2006. Approved baseline methodology: Avoided emissions from organic waste through alternative waste treatment processes. AM0025/ Version 03. www.unfccc.org.

Voet E. van de (1996): Substances from cradle to grave - Development of a methodology for the analysis of substance flows through the economy and the environment of a region. Leiden University.

Woldeselassie, O., Mehreteab, T., Sirak, M., Drescher, S., 2005. Benefits and risks of the use of organic matter from the Asmara landfill in agriculture. Final report, Sandec Dübendorf, Asmara