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Global Change and Ecosystems

Del. 4.1.9 A report evaluating various ecosan system alternatives for urban areas by multi criteria analysis – using Accra, Ghana as a case study

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SWITCH Deliverable Briefing Note

SWITCH Document

Del. 4.1.9 A report evaluating various ecosan system alternatives for urban areas by multi criteria analysis – using Accra, Ghana as a case study

Audience

This document is targeted at stakeholders in sanitation provision for peri-urban areas in developing countries, in particular policy makers, local government staff, planners, civil/sanitary engineers, etc. More particularly it might be of use to the Learning Alliances in the various SWITCH demonstration cities.

Purpose

The purposes of the report are:

1. To provide stakeholders in sanitation projects with an easy-to-follow methodology which helps to find "the best" (most sustainable) sanitation system solution for a given urban area.
2. To demonstrate how exactly this selection methodology works, using Accra (Ghana) as an example.
3. To highlight that the range of sustainability criteria and their weightings are important and different for the different parts of the sanitation system.
4. To provide a tool to the Learning Alliance in Accra to assess different sanitation options to improve the sanitation situation in Accra (with a focus on excreta management in the peri-urban areas).

Background (one to two paragraphs describing the research and why it was needed)

There are nowadays a large number of different sanitation technologies for urban areas available, be they conventional or "non-conventional", such as ecological sanitation (ecosan). Ecosan is a new paradigm in sanitation which aims to enable safe reuse of sanitised excreta and greywater and be sustainable in all aspects.

Many researchers are currently developing methodologies to select the best sanitation option in order to simplify the choices of decision makers. The decision-making process quickly gets complex, and the aim of Decision Support Systems (DSSs) is to support people in taking decisions. Common elements of such DSSs are typically:

- A design of each option is needed for evaluation and decision making (the more detailed the design, the more accurate the remainder of the procedure)
- To make a final choice, multiple-criteria decision analysis (MCDA or MCA) is used.

There is a lack of worked examples on how the MCA could be used to decide on the best sanitation system for the low-income areas in developing countries. This report gives an overview of the proposed methodology to carry out the MCA, and then provides a worked example by using the excreta management system in the peri-urban areas of Accra in Ghana as a case study.

Potential Impact
The impact of this report, if put into practice by the Learning Alliance of Accra (or others) would include:

- Avoiding unwise choices of sanitation systems;
- Avoiding wasting of money (donor funds or local funds) by investing into sanitation systems which are less sustainable than others would have been; and
- Creating greater awareness of sustainability aspects and how to work with them in practice
- Creating awareness for the many different available options for sanitation (conventional or ecological sanitation).

Issues

- It was difficult to access data, maps reports and stakeholders just by e-mail without traveling to Accra (the bulk of this work was carried out by the MSc student Kalyani de Silva, who did her work as a desk top study).
- The MCA results (scores of the two-short-listed options) presented in this report are only indicative because we only had access to five experts which were not very familiar with the sanitation in Accra. To get more reliable results (scores), the MCA should be repeated by using a greater number of Accra-based experts and stakeholders.

Recommendations

- Publish this deliverable on the SWITCH website and make it known to the Learning Alliance.
- Include a presentation of this deliverable in the next LA meeting, check usefulness for stakeholders.
- Use this deliverable as input for other deliverables in this work package (4.1.10, 4.1.11 and 4.1.17).
- Test the methodology proposed also on other SWITCH demonstration cities.

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1. Foreword

This report is mainly based on the work conducted by Ms. Kalyani de Silva in her MSc thesis (September 2006 to April 2007) at UNESCO-IHE Institute for Water Education, which was funded by the SWITCH project (de Silva, 2007). The mentors of Ms. de Silva were Dr. Elisabeth von Münch (UNESCO-IHE; the principal author of this report) and Dr. Adriaan Mels (Wageningen University), who are both team members of the SWITCH project, sub-project 4.1.

2. Introduction

There are nowadays a large number of different sanitation technologies for urban areas available, be they conventional or "non-conventional", such as ecological sanitation (ecosan). Ecosan is a new paradigm in sanitation which aims to enable safe reuse of sanitised excreta and greywater (Winblad and Simpson-Hébert, 2004) and be sustainable in all aspects.

The nitrogen, phosphorus and organic matter in sanitised urine and faeces can be used in agriculture as a fertiliser and soil conditioner, respectively. This aspect is particularly important for poor people living in areas of nutrient-depleted soils (e.g. in sub-Saharan Africa) who cannot afford to purchase artificial inorganic fertiliser. In general, ecosan options do not rely on the soil for storage of excreta and infiltration of urine, and therefore significantly reduce the danger of leaching of nitrate and pathogens into groundwater (as may occur from the pits of pit latrines). A further advantage is that ecosan technologies can typically be implemented at much lower costs than conventional water borne sewers.

Ecosan interventions also have the potential to contribute to a whole range of Millennium Development Goals (Millennium-Project (2005), Rosemarin (2003), von Münch *et al.* (2006)), e.g. those related to basic sanitation provision, improvement of lives of slum dwellers, reduction of hunger, extreme poverty and child mortality. Higher agricultural yields of fields fertilised with ecosan products can lead to a lower incidence of malnutrition and hence lower levels of morbidity.

Many researchers are currently developing methodologies to select the best sanitation option in order to simplify the choices of decision makers (e.g. with so called Decision Support Systems), for example Niwigaba *et al.* (2006). Once it has been decided to follow an ecosan approach, there are many different technology options available within the ecosan approach. For example, if we only consider the toilet type, the following non-exhaustive range of options exists:

- Conventional water flush toilets (no urine separation)
- Vacuum toilets (with or without urine separation)
- Urine-diversion water flush (urine collected pure or with washwater)
- Urine-diversion dehydrating (UDD) toilets
- Composting toilets (with or without urine diversion)
- Conventional pit latrines or ventilated improved pit latrines

The choice of toilet will affect other related technologies for transport, treatment and reuse of excreta and greywater. From a technology point of view, sanitation encompasses:

- Excreta management
- Greywater management
- Drainage
- Solid waste management

So the decision-making process quickly gets complex, and the aim of Decision Support Systems (DSSs) is to support people in taking decisions. There are many existing and emerging DSSs in the field of wastewater treatment and sanitation (e.g. the EU funded Zer0-M project (http://www.zer0-m.org/) or Castellano (2007))

Common elements of such DSSs are typically:

- A design of each option is needed for evaluation and decision making (the more detailed the design, the more accurate the remainder of the procedure)
- To make a final choice, multiple-criteria analysis is used.

In the literature, the term multiple-criteria decision analysis (MCDA) is commonly used. Within the MCDA methodology, there are a number of sub-methods that can be used; this has been reviewed for example in Pietersen (2006).

We have selected the most basic, intuitive sub-method of the MCDA, which is simply based on using weighted scores. This report gives an overview of the proposed methodology and then provides a worked example by using the peri-urban areas of Accra in Ghana as a case study.

3. Description of methodology to conduct basic MCA

We propose the following methodology for evaluating various ecosan system alternatives for urban areas by multi criteria analysis (Steps 1 to 5 have also been described in detail in von Münch and Kennedy (2007)):

- Step 1: Analyse existing sanitation situation
- Step 2: Define possible sanitation options and selection criteria (based on the findings of Step 1)
- Step 3: Short-list a small number of options based on the selection criteria
- Step 4: Prepare concept designs for the short-listed options
- Step 5: Prepare cost estimates based on the concept designs (e.g. using basic cost equations proposed in von Münch and Kennedy (2007))
- Step 6: Carry out the MCA, which consists of:
  - Defining general and specific sustainability aspects for each part of the sanitation system (Part A to E, see Figure 3-1), including indicators of the sustainability aspects
  - Enrolling experts in the field or relevant stakeholders
  - Letting the experts fill in the MCA matrix, including weightings for the general aspects and scores for the options on the specific aspects
  - Analysing the results by calculating weighted average values across all the experts
- The end result is a ranking of options (the option with the highest score should be the recommended option).

We advocate applying a ‘systems approach’ to sanitation and as such, five major parts of the sanitation system ought to be distinguished (Figure 3-1):

- Part A: Household toilets
- Part B: Collection and transport of excreta from households to treatment site
- Part C: Treatment and storage of excreta at (semi-) centralised location
- Part D: Transport of sanitised excreta from treatment site to agricultural fields
- Part E: Reuse of excreta in agriculture (sale of fertiliser)

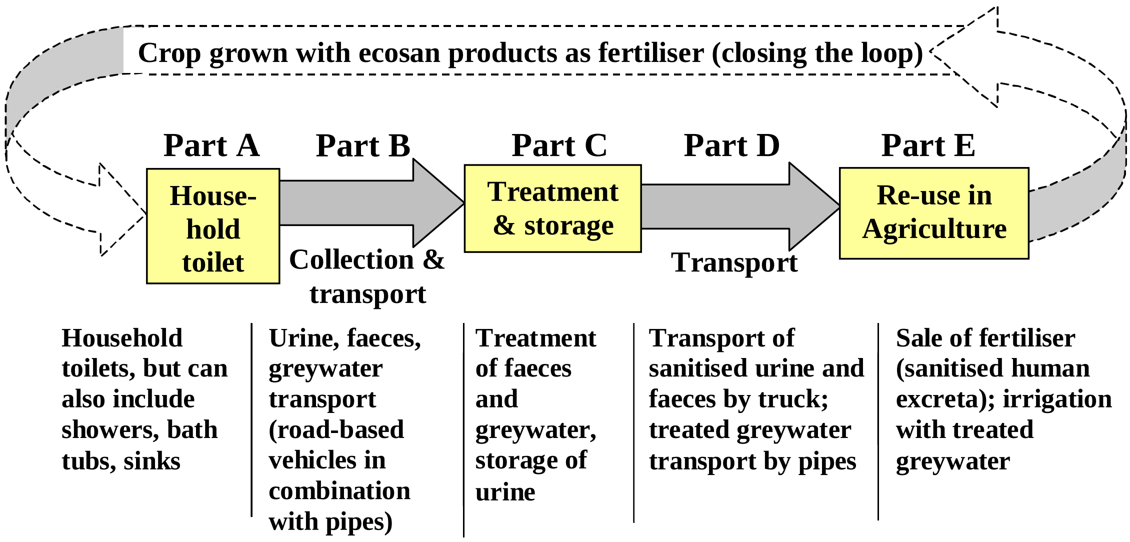

Figure 3-1. Sanitation system components which should be included in the MCA.

It is clear that this methodology cannot be applied for selecting the best option for <u>any</u> (hypothetical) location, because:

- The selection criteria and short-listed options will be dependent on local circumstances: e.g. if an area has a water shortage problem then one selection criterion could be "should not use water for flushing" which would rule out certain options; whereas another area may have abundant water, so they would not have the same selection criterion. Other examples include wealth of population, driver for sanitation (public health or environmental protection), availability of trained staff, etc.
- The specific aspects on which the options will be scored on, have to be set up <u>after</u> a concept design has been carried out, because they will be specific to the type of system selected (e.g. a transport system using pipes will have different specific aspects than a transport system using trucks). A concept design cannot sensibly be carried out for a hypothetical location but needs real data to be realistic.

For these reasons, the remainder of the paper uses the specific example of the peri-urban areas in Accra (Ghana) to illustrate the proposed method for MCA. It should be stressed that here we limited our analysis and concept design to the excreta management system for simplicity reasons. We did not include greywater management – for reasons of simplicity and because in the peri-urban areas of Accra, excreta management is thought to have more urgency compared to greywater management with respect to public health protection.

4. Illustration of proposed MCA methodology for peri-urban areas in Accra (Ghana)

4.1. Step 1: General description of the Accra peri-urban areas

The total estimated population and population density of Ghana in 2006 according to CIA (2007) are 22.4 million and 0.94 people/ha respectively. The estimated population growth rate in 2006 is 2.07% per annum. The total area of Ghana is 239,460 km^2. Arable land area in Ghana is 18% of the total area.

Accra is the capital city of Ghana, which is a West African (English speaking) country (see Figure 4-1) and is the most urbanised city in Ghana. It has a population of 1.6 million and a population density of 83 people/ha (RUAF, 2006). The urbanization has been mainly due to the rapid increase in population as a result of the concentration of industry, manufacturing, commerce, business, education, and administrative functions. Accra lies within the coastal zone with low annual rainfall averaging 810 mm distributed over less than 80 days (RUAF, 2006).

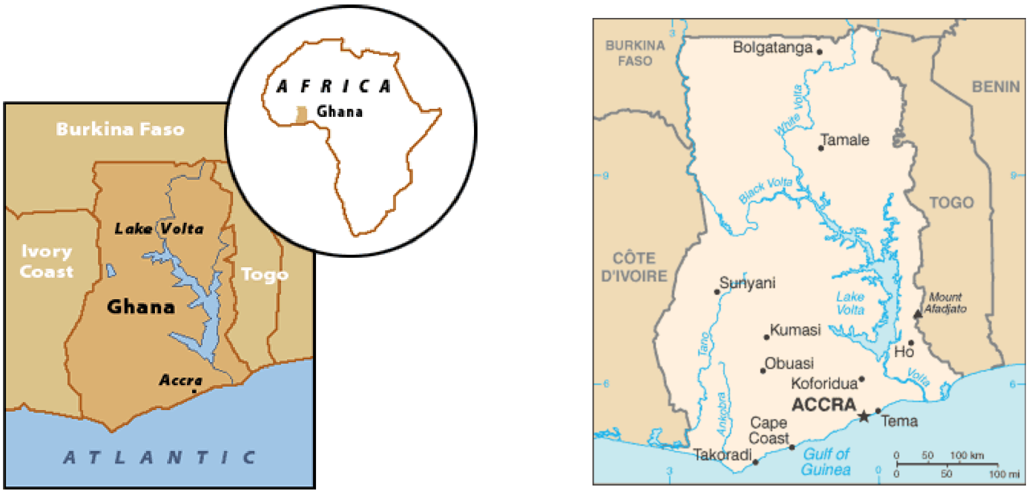

Figure 4-1: Ghana map (Source: http://www.cia.gov/cia/publications/)

The Greater Accra region occupies a total area of 3,245 km^2 or 1.4% of the total area of Ghana (GSS, 2002). The Accra Metropolitan Assembly (AMA) has a population density of 82.9 people/ha and includes the CBD (Central Business District). The total area of AMA is 200 km^2. All the towns outside of AMA can be called peri-urban towns of Accra. The population of greater Accra is 2.9 million in 2000 and it comprises of five areas/districts: They are Accra Metropolitan area (AMA), Tema municipal area, Ga district, Dangme West district, and Dangme East district (GSS, 2002).

The concept design and MCA was carried out for AMA in particular because:

- Urban agricultural activities are mostly taking place in this district
- The area is highly urbanized with a population density of 83 people/ha.
- High inequalities exist in the distribution of income in AMA due to migrants in different income levels. Therefore, the residents can earn additional income, e.g. for their daily food requirements, by using low-cost natural fertilisers (sanitised faeces and urine) in urban agriculture.

Maxwell *et al.* (2000) reported that the average household size in AMA is **4.5**. In Accra between 13 **– 16%** of the urban and peri-urban dwellers engage in some form of agricultural activity including livestock and poultry production. These figures (marked in bold above) will be used in the concept design (see Section 4.4).

Households in AMA use mainly public toilets[1] (32.7%), VIP, pit and bucket latrines or water closets in-house (Figure 4-2 and GSS (2002)). Even though there are by-laws for all new dwellings to convert to either water closet or VIP toilets, AMA has a very high proportion of households still using bucket latrines (12.7%). In addition, still there are people who use open defecation even in the urban centres (along the beaches or water courses, bushes, and gutters).

It should be pointed out that public toilet does *not* count as improved sanitation for counting in the Millennium Development Goals (WHO/UNICEF, 2006)

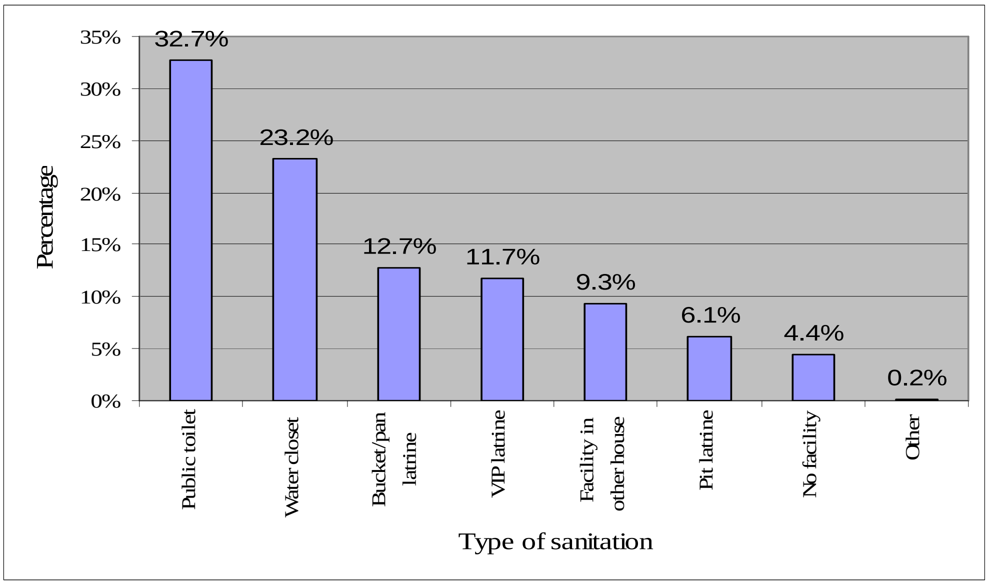

Figure 4-2: Types of sanitation systems for excreta management use in AMA (GSS, 2002)

There are no adequate facilities for collecting and treating greywater in the urban and peri-urban areas in AMA. Over half of the households in AMA use gutters (53.2%) to dispose the liquid waste/ greywater produced from kitchen and bathrooms (Figure 4-3).

[1] VIP, pit, bucket and pour flush toilets

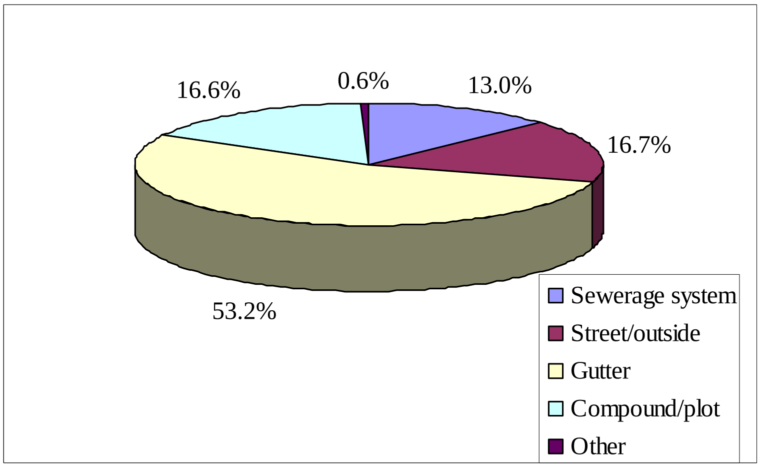

Figure 4-3: Means of greywater disposal in AMA (GSS, 2002)

The poor health situation of Accra's residents, especially those in the low-income bracket, which is the result of the inadequate sanitation system and unsafe wastewater reuse practices, has been well documented and analysed by others (e.g. Suleiman (2007) and Lunani (2007), see also Box 1).

Box 1: Main conclusions from the assessment of the public health risk of the Accra Urban Water System (Lunani, 2007)

1. Some of the potential transmission routes originating from the Accra Urban Water System were identified. From the sanitation system, the routes identified were: recreational swimming in contaminated beaches; flooding of the Odaw drain; the UASB treatment plant; faecal septage disposal place and open drainage channels. From the water supply system, the routes identified were the water treatment plants due to errors in the treatment processes and the contaminated distribution system.
2. The established waterborne disease incidence was highest in Ashiedu Keteke sub-metro and lowest in Ablekuma sub-metro.
3. The urban water system contributed greatly to the endemic waterborne disease incidence in AMA. It contributed 75% of the rotavirus cases; 37% of *Campylobacter* cases; 21% of *Ascaris* cases and 3% of *Cryptosporidium* cases. Rotaviruses contributed 78% of the total cases from risk assessment.
4. The disease burden from the Accra urban water system is substantial. There was a total of 28, 531 DALYs, with sanitation contributing 91%. This is an equivalent of 3.0*10-2 DALYs pppy which is 30,000 times higher than the reference value of 1.0*10-6 DALYs pppy, set by WHO. In addition, rotaviruses dominated the DB.
5. The risk from AUWS would have a significant impact to the community as shown in table 7.1. The largest impact to the Accra community would arise if children ingest contaminated sand/water while playing near open drainage channels and if people swim in contaminated beaches. Overall, the sanitation pathway was judged to be of more importance than the water supply pathway.

The main source of drinking water in AMA for 90.5% households is water supplied in pipes either inside or outside the house (community stand post). There are about 4.7% of households in this area who utilise groundwater sources such as wells and bore holes for their drinking water (see Figure 4-4). The quality of the groundwater may be compromised by the many onsite sanitation facilities.

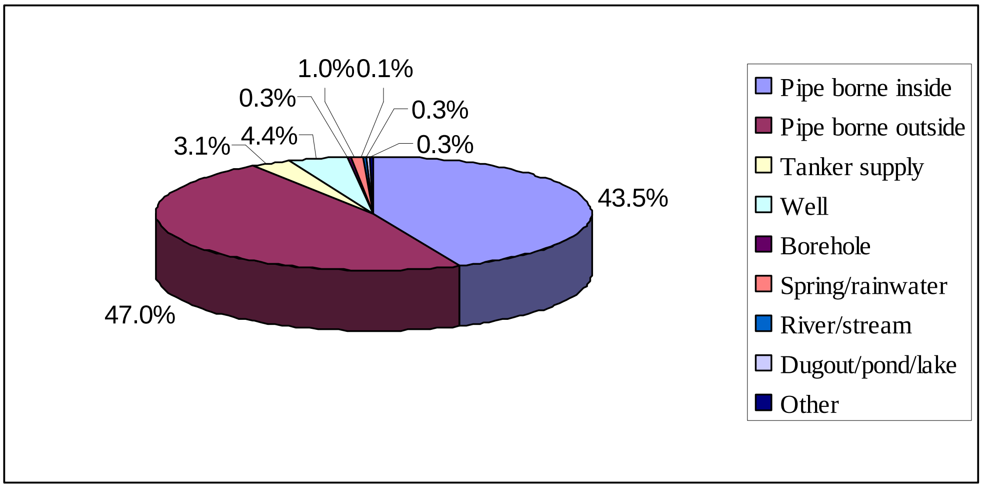

Figure 4-4: Types of sources of drinking water in AMA (GSS, 2002)

The key characteristics for Ghana and AMA with respect to general country data, water and sanitation aspects and urban agriculture are summarised in Table 4-1, Table 4-2 and Table 4-3. The analysis of urban agriculture practices is relevant because urban agriculture opens up reuse opportunities for treated excreta, an aspect which is particularly important for ecosan approaches (see also Part E in Figure 3-1).

Table 4-1. Summary of general country data for Ghana (CIA, 2007)

Parameter	**Value for Ghana**
Population density (2006 estimate)	0.94 people/ha
Annual growth rate (2006 estimate)	2.07% p.a.
GDP/capita (2006 estimate)	$ 2,600
Fertility rate (2006 estimate)	3.99/woman
Infant mortality rate – deaths per 1,000 live births (2006 estimate)	55
Literacy rate (2004 estimate)	74.8%
Life expectancy at birth (2006 estimate)	58.8 years

Table 4-2: Summary of key characteristics for AMA with respect to sanitation and water supply

Description	**Value for Accra Metropolitan Assembly (AMA)**
Annual rainfall	810 mm (tropical wet and dry climate)
Average temperature	27.1°C
Population	1,658,937
Area covered	200 km^2
Population density	83 people/ha
Average household size	4.5
Major religious group	Christian – 83 %
Existing greywater disposal options	About 53 % dispose to gutter, only 13 % dispose to sewer
Constraints against sanitation improvement	Lack of finance, lack of appropriate technology, perception of communities, culture, attitudes of landlords, users and policy makers
Existing strength towards improvement of sanitation systems	Public awareness about sanitation problem, willingness of user participation, payment and contribution, local government support
Water supply methods	47 % houses connected to pipe water, others: stand pipe, tanker, river, stream, lake, groundwater

Table 4-3: Summary of urban agriculture characteristics in Accra

Description	Value for Accra (or AMA)
Rainfall (mm/yr)	810
Soil quality	Unfertile soil
Type of farming	Irrigated, livestock, aquaculture, open space, backyard and seasonal crops
Type of crop	Maize, lettuce, spring onions, beans, tomato, rice, cassava, cabbage, spinach, cauliflower, cucumber
Type of water supply	River, drain (wastewater), stream, shallow well
Fertiliser use	Artificial inorganic (15-15-15, urea, AS, MOP), animal manure (poultry)
Main constraints	Access for water, high cost for fertiliser, lack of capital, lack of technology, market for production, lack of space, pest & disease threat
Current cost of urea (€/ton)	218
Country-wide fertiliser use	19.2 kg/ha/year
% of residents engaged in urban agriculture	For AMA 10-16 %

Table 4-4: Summary and possible role of ecosan to address constraints in urban agriculture in Accra

Constraints for urban agriculture	Impact of ecosan to reduce constraint	Further approaches and solutions to lift constraints
Access for water	Greywater treatment and reuse	Save water by not using it to flush water
Consider rainwater harvesting	Soil conditioner increases water holding capacity (less water needed for same yield)	Introduce UDD toilets in low-income urban areas
Implement projects to safely reuse greywater even at household level	High cost for fertiliser	Use of human urine as a fertiliser
Use of sanitised human faeces as soil conditioner	Easy to find these natural fertilisers locally at low cost	Launch awareness campaigns to educate farmers in practices to ensure sustained soil fertility
Market for production		
Lack of capital	Ecosan-derived fertilisers much cheaper than artificial fertilisers	
Lack of space	Higher yield on smaller areas; hydroponics reduces space requirement	
Lack of technology		Government-supported education campaigns; school gardens
Pest & disease threat	Urine has been used to kill some insects	
Lack of secure tenure		Need to form farming groups and negotiate with land owners

4.2. Step 2: Define available low-cost sanitation options for Part A of the sanitation system and selection criteria

Only options that classify as “improved sanitation” (WHO/UNICEF, 2006) are considered in the list of available sanitation options for excreta management. We have considered the following four options as low-cost, improved sanitation (excreta management) options for AMA (for Part A of the system, see also Figure 3-1):

Option 1: Ventilated improved pit latrines (KVIP/VIP)[2]: This type of toilet is commonly used in this area.

Option 2: Urine-diversion dehydration toilet (UDD): For this study, we selected the double vault UDD type and not the single vault type because it gives a higher degree of sanitisation (when one vault is full the other vault is used for collection of excreta). After one year storage time, the excreta is mostly sanitised and can be removed from the vault easily. Although in our conceptual design, we assumed that all excreta is transported to the storage site, in an actual situation the households can utilise them easily as soil conditioner after one year of storage time in their own vaults.

Option 3: Simple pit latrine (with or without lining): This type of toilet is used by a considerable percentage of households in AMA – either in a public toilet or as a household toilet (see Figure 4-2).

Option 4: Pour-flush or water closet (WC) toilet: This type of toilet can be connected to either a waterborne sewer system or a septic tank and soak away. In the waterborne system, wastewater is collected through a centralised sewer system and treated and/or disposed. When the toilet is connected to the septic tank, the faecal sludge from the septic tank has to be removed periodically and given appropriate treatment. Normally this type is used by high income families only unless the pour-flush toilet is connected to a pit.

Notes related to the available excreta management options:

- All options could be implemented as either individual household toilets or shared public toilets.
- All options, except Option 2, require faecal sludge management because they produce wet faecal sludge.

We used the following criteria for short-listing of the sanitation options (for Part A) of the Accra Metropolitan Assembly (AMA):

- Groundwater and surface water sources should be protected from pollution by human excreta (pathogens and nitrate).
- Investment and operation and maintenance cost are very important criteria for sanitation technology selection for poor households in an urban area.
- Since water supply is unreliable in AMA (see Section 4.1), water should not be wasted for toilet flushing and transport of waste.
- Odour and flies should not be present.
- The possibility to use sanitised human excreta for urban agriculture would be an advantage.

[2] Although Accra people say KVIP (Kumasi ventilated improved pit latrine), we use the established abbreviation VIP since there is no significance difference between them.

4.3. Step 3: Short listing of sanitation options

According to the selection criteria listed above, the following two sanitation options for Part A are disqualified.

> Option 3: Simple pit latrine (with or without lining): This type of toilet infiltrates the urine and pit leachate to the soil which can lead to pollution of groundwater. Some residents in AMA use groundwater as drinking water in AMA (see Figure 4-4). When considering the whole downstream process of the pit latrine option, it can cause pollution of the surface water by discharging effluent from the faecal sludge treatment plant (if faecal sludge is treated at all). Odour and flies are also a common problems related with this type of toilet.
>
> Option 4: Pour-flush or water closet toilet: Pour-flush latrines have a higher water use compared to the other options which results in greater wastewater production and wasting of good quality water[3]. If connected to a septic tank, the septic tank needs to be desludged periodically, otherwise faecal sludge might overflow. High operation costs are associated with the emptying. Investment costs are also relatively higher for this option than others. If the pour-flush toilet is connected to a pit only, then groundwater pollution can occur. This option is therefore ruled out.

The only two remaining sanitation options out of the four options listed above are Option 1 (ventilated improved pit -VIP) and Option 2 (double-vault urine-diversion dehydration (UDD) toilet).

Note: Option 1 and 2 consist of more than just the toilet (see Table 4-5), so when we refer to option 1 as the “VIP toilet option” we mean “VIP toilet plus downstream processing” (the same applies for Option 2).

4.4. Step 4: Concept design

The components of our concept design are summarised in Table 4-5, and they are based on the following assumptions:

- Each household would get their own toilet rather than having to share a toilet with other households. This implementation level was used because it is more comfortable and hygienically safe to use one toilet for one household. However, it costs more.
- The average household size (who will have one toilet) is considered as 4.5 (see Section 4.1.
- Sufficient space outside of the house or inside of the house is available for construction of a toilet for each household.
- Sufficient access roads or paths are available to household toilets for collection and transport of faecal sludge, dried faeces and urine, respectively.
- 16 % of the total urban population in AMA is used for the design, because this is the approximate population who is engaged in urban farming in AMA (total population of AMA is 1.6 million and 16% of this is around 265,000; see Section 4.1). This population of urban farmers is selected because urban farmers can use their own sanitised faeces and urine for farming activities at low cost or they can buy these fertilisers easily in their own areas. However,

[3] Most of the time drinking water is used for flushing the toilet.

one problem with this assumption is that it is unknown where exactly these 265,000 people in AMA live: they are scattered over the entire area of AMA.

- Typical transport distance (for Part B) will be approximately 10 km.
- Farmers are willing to buy treated sludge/ sanitised faeces/urine and are willing to transport it at their own cost (distance for Part D approximately 10 km).
- We used the work of Mayumbelo (2006) as a starting point. In the following, we will highlight where we made changes to his design. He had also short-listed two options for peri-urban areas in Lusaka, Zambia, namely VIP latrines and UDD toilets (single vault).

The urine-diversion dehydrating (UDD) toilet is one of the numerous possible toilet types that can be used within an ecosan approach. It separates the urine and faeces in the toilet, and the two substances are stored and treated separately from each other (GTZ, 2007). The faeces are air dried in a ventilated single vault or double vault configuration (the second vault is used once the first vault is full), with the aim to achieve pathogen kill and volume reduction. As mentioned above, the double vault system was chosen here because of its safer mode of operation compared to a single vault system (but it is also more expensive).

UDD toilets do not use water for flushing, which is important for areas with unreliable water supply, such as the peri-urban areas of Accra. UDD toilets are also quite simple to operate (compared to some composting toilet types), resilient to floods, and the toilets can be located on any level inside the house. The dried faecal matter from a UDD toilet is less offensive and odorous than faecal sludge from pit latrines because faeces are not combined with urine or water. – For these reasons, the UDD toilet is used to represent Part A of the ecosan option (Option 2) in this cost comparison.

For Option 1 Part C, we assume only one anaerobic digester (with sludge drying beds) to treat the faecal sludge, because it is costly to construct and maintain more plants. For Option 2 Part C, we assumed that there are three centralised storage points at equal distance for easy transport for urine and faeces. The map in Figure 4-5 shows the location of the anaerobic digester treatment plant for Option 1 (VIP) and proposed locations for storage of faeces and urine for Option 2 (UDD) in AMA.

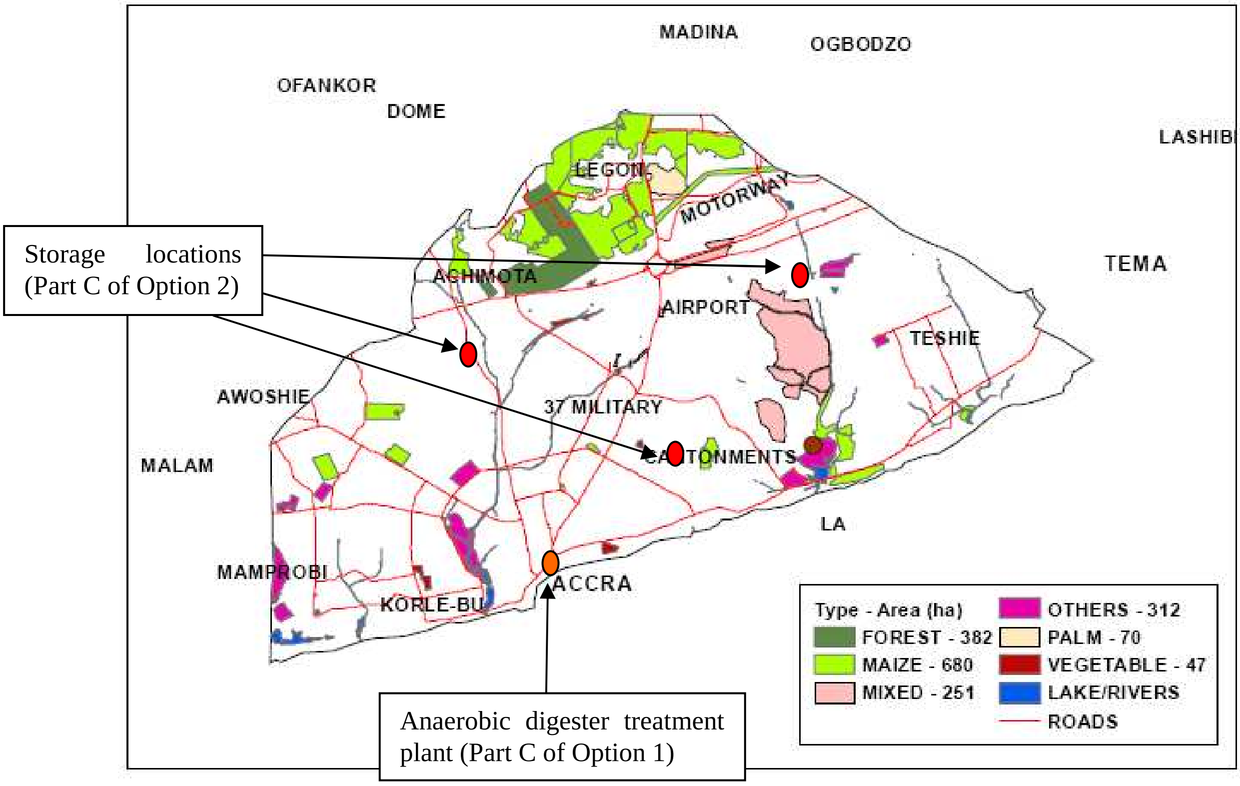

Figure 4-5: Locations of anaerobic digester treatment plant for faecal sludge (Part C of Option 1) and storage points for urine and faeces (Part C of Option 2) in AMA.

Table 4-5: Summary of concept design of two short-listed options[4] for AMA (population of 265,000 and average household size 4.5). Further details are provided in de Silva (2007).

	Items which have an impact on capital cost		**Items which have an impact on O&M cost**	
	Option 1 (VIP + downstream processing)	**Option 2 (UDD + downstream processing)**	**Option 1 (VIP + downstream processing)**	**Option 2 (UDD + downstream processing)**
Part A: Household toilets	VIP toilets (*59,000* toilets)- outdoor toilets	*Double vault* UDD toilets (*59,000* toilets) – indoor toilets	None	Additives to faeces chamber after defecation is assumed to be available for free
Part B: Collection and transport of excreta	*Four* vacuum tankers to transport the faecal sludge to the treatment plant	• *One* open truck to transport dried faecal matter • *Seven* open trucks to transport urine barrels • Plastic barrels of *100 L* (assumed urine is collected once in every 14 days) for the urine storage at UDD toilet (2 barrels per toilet) • Assume there are *three* centralised storage points at equal distance for easy transport for urine and faeces (see Figure 4-5)	Removing faecal sludge from the pit once it is full (includes fuel, maintenance on trucks, salary and overheads)	Transport cost for faecal matter and urine barrels; includes fuel, maintenance on trucks, salary, overheads. Emptying of vaults (should be similar to garbage collection services).
Part C: Treatment and storage of excreta	One (because it is costly to construct and maintain more plants) centralised faecal sludge treatment plant (*bio gas digester treatment plant with sludge drying beds*) (see Figure 4-5 for location)	• No treatment required, only storage: • Dried faecal matter storage: Dried faecal matter is stored for 6 months on 2 m high piles on concrete slabs and covered with tarpaulin sheets during the rainy season to avoid leaching the nutrients • Urine storage tanks: assume urine will be stored in plastic tanks for 2 weeks to allow collection for re-use	Staff labour for operating the faecal sludge treatment plant (use figures for cost of treatment from *Accra*).	No treatment is needed; only further storage (increases pathogen die-off). Assumed five workers managing the incoming and outgoing flows of material.
Part D: Transport of sanitised excreta	Open trucks could be used but are not included in cost estimate because we assume that in Accra, the burden of transport would be shifted to the farmers who buy the fertiliser			
Part E: Reuse in agriculture	No capital cost items (buying of land is not included)		Sale of treated sludge (compost)	Sale of ecosan products (sanitised faeces and urine)

[4] This conceptual design is principally the same as the one proposed in von Münch and Mayumbelo (2007). Any differences are highlighted in italics.

4.5. Step 5: Costing of short-listed options

In Step 5, a cost analysis has to be performed, based on the concept design of Step 4. By calculating the capital and annual operating costs, the overall project net present value (NVP) can be determined. This is important because in Step 6, the experts have to give a score to the economic aspects of the two options. In order to do so, they need to know the NPV, or at least they need to know which of the two options has the lower overall cost.

The work of de Silva (2007) provides details for the cost estimates, including a basic sensitivity analysis for different cost components (see also summary tables in Appendix 2: Costing data (used for calculating NPV values)). The final outcome of the cost analysis is shown in Table 4-6 below.

Observations made from costs figures are:

- Option 1 has lower NPV and is therefore more financially attractive than Option 2.
- Operation and maintenance cost for Option 2 is lower than for Option 1.

Table 4-6: Summary of cost and NPV for Option 1 (VIP system) and Option 2 (UDD system)

Parameter	Option	
	Option 1 (VIP system)	Option 2 (Double vault UDD system)
Total capital costs (million €)	7.1	10.4
Capital costs per capita (€/cap)	27	39
Total O&M cost (million €/yr)	0.6	0.5
O&M cost per capita (€/cap)	2.2	2.1
Total NPV (million €), based on 12 % discount rate and 10 year project lifetime	10.5	13.5

4.6. Step 6: Conducting multiple-criteria analysis (MCA) for short-listed options

The MCA is conducted by weighting and scoring options against a set of (sustainability) criteria, which allows the determination of a final score for each option. Other authors have already developed relevant lists of criteria to be used when analysis sanitation systems. We took the work of Kvarnström and af Petersens (2004) as a starting point. They had proposed a list of sustainability indicators, divided into six broad categories[5]:

- Criterion 1: Social aspects
- Criterion 2: Technological aspects

[5] Kvarnström and af Petersens (2004) used only five categories, because social and institutional aspects where grouped into the same category.

- Criterion 3: Economic aspects
- Criterion 4: Physical environment aspects
- Criterion 5: Health aspects[6]
- Criterion 6: Institutional aspects

Each of these aspects has a number of sub-criteria and indicators, and an example list of these is provided in Kvarnström and af Petersens (2004), together with the explanations shown here in Box 2.

We have now *extended and applied* this work of Kvarnström and af Petersens (2004) in the sense that:

- We have defined different sub-criteria at the level of the five different sanitation parts (Part A to E), e.g. cost per person, risk assessment etc.
- We have developed sub-criteria specific for the two options being compared in Accra, i.e. we made the criteria context-specific, as was recommended by Kvarnström and af Petersens (2004).
- We have given different weightings to different sub-criteria of the sanitation component: for example, social aspects would be more important than technical aspects for Part A of both options (but less important for Part C).

Our own list of sub-criteria for the different components of the sanitation system is shown in Table 4-7 (further details regarding the indicators is provided in Appendix 1).

Box 2: Explanations related to the criteria list proposed by Kvarnström and af Petersens (2004)

It is impossible to identify a complete list of factors that will affect the sustainability of a sanitation system without knowing the specific context. Moreover, a list of criteria will not provide easy answers in the decision-making process but it will help narrow down the discussion. The attempt here is therefore to try and present an extensive range of different criteria that might be of importance in different contexts.

The list would need to be reduced/expanded for each specific case. There will also be a need to identify locally relevant criteria that do not appear on this suggested list, irrespective of level of intervention, in close cooperation with all relevant stakeholders, the current legal framework and current cultural practices. The content of the list may depend on the level at which the criteria are used (household, neighbourhood, community, municipality, government, international donors etc.). Moreover, the list proposed here does not take into account the fact that certain criteria might need to be considered at different stages in the planning process and that there might be a need to weigh criteria against each other. For the specific planning case there is also a need to connect this criteria list to a sanitation planning tool adapted for the level of intervention. A list of criteria could also serve as a checklist to identify knowledge gaps for different sanitation systems, with respect to their sustainability in a given setting.

Below we present what we think might be important criteria, with which one could assess different sanitation systems before deciding what approach/system/technique would be the most suitable in a given setting. This list of criteria is based on the work of several different authors who have worked in this area (e.g. Balkema, 2003; Hellström et al., 2000; Urban Water, 2004; Larsen & Gujer, 1997; Larsen & Lienert, 2003; Lennartsson, 2004) as well as on the discussions held

[6] Under the criterion "health aspect" for Part E, we have included "risk assessment" as a sub-criterion (two sub-criteria). Such risk assessments are further described in WHO (2006).

during the meeting. They have been divided into five broad categories of criteria which we believe cover the main areas to be addressed by a sanitation system. The list will hopefully encourage discussion and we would welcome all feedback related to it.

Table 4-7. Listing of detailed aspects (sub-criteria) for five different parts of the sanitation system (based on the work of Kvarnström and af Petersens (2004) – see Appendix 1 of that document). Appendix 1 of this documents provides indicators and further comments on each aspect.

	Part A - Toilet device	**Part B - Collection and transport**	**Part C - Treatment and storage**	**Part D - Transport of treated material**	**Part E - Reuse of treated material in agriculture**
S	**Social aspects**				
1	Acceptability (comfort)	Willingness of people to work in collection/transport business	Potential devaluation of area & inconvenience to neighbourhood	Reliability of collection & transport (private or Municipality)	Potential for cultural barriers to use products
2	Personal security (indoor versus outdoor)	Reliability of collection	Willingness of workers to work at this site	Willingness of workers to work at this site	Farmers willingness to utilise the fertiliser
3	System complexity				
T	**Technological aspects**				
1	System robustness (danger of pit collapsing, structural stability)	Use of water for pumping	System robustness (risk of process failure)	Complexity of transport	Potential for impurities in final products grown with that fertiliser
2	Robustness of use of system (effect of abuse of system)	Requirement for energy (operate pumps)	Use of local material for construction	Access road width required	Ease of storage of fertiliser (for farmers)
3	Robustness against extreme conditions (flooding)	Complexity of collection	Ease of system monitoring	Impact on roads and increase traffic	Quality of fertiliser or soil conditioner
4	Use of local material for construction	Access road width required	Potential for energy generation (biogas)	Requirement for specialised equipments	Ease of application of fertiliser (need for new machinery)
5	Durability/lifetime	Impact on roads and increase traffic	Durability/lifetime		
6	Flexibility/adaptability (existing ground water level, geology)		Flexibility/adaptability (existing ground water level, geology)		
7	Potential for resource recovery (nutrients)		Potential for resource recovery (nutrients)		
8	Complexity for construction and O&M		Complexity for construction & O & M		
9			Reliability during rainy season		
10			Space requirement		
E	**Economic aspects**				
1	Capital cost	Capital cost	Capital cost	Capital cost	capital cost

	Part A - Toilet device	Part B - Collection and transport	Part C - Treatment and storage	Part D - Transport of treated material	Part E - Reuse of treated material in agriculture
2	O & M cost	O & M cost	O & M cost	O & M cost	Lower expenses for not having to buy chemical fertiliser
3	Capacity to pay for user	Capacity to pay of user for collection	Potential for income from biogas	Capacity to pay for farmer for transport	Income from higher yield by fertiliser use
P	**Physical environment aspects**				
1	Odour	Odour during collection	Potential impacts on receiving water bodies	Odour during transport	Odour during storage of urine at farm
2	Potential of groundwater contamination	Noise during collection	Potential of groundwater contamination	Noise during transport	Odour during application of urine at farm
3	Use of natural materials for construction and O&M	Odour during transport	Odour	Pollution from trucks (dust, CO_2 emission)	Odour during storage of solids at farm
4	Potential to devaluation of area & inconvenience to neighbourhood	Noise during transport	Noise		Odour during application of solids at farm
5		Pollution from trucks (dust, CO_2 emission)			Risk of over-fertilisation and resulting run-off
H	**Health impacts**				
1	Potential of contact with fresh excreta	Potential health risk during collection & transport	Potential for flies to transmit pathogens	Potential health risk during transport	Potential health risks for consumers of fertilised foods
2	Potential of transmit pathogens through flies		Potential health risks for workers		Potential health risk during handling of fertilisers for farmers
I	**Institutional aspects**				
1	Skill necessity (locally) for construction and O & M	Potential to private sector involvement	Resources necessity (labour, material)	Capacity building required for transport	Capacity building requirements for farmers
2	Training requirements for users	Awareness amongest transport stakeholders	Capacity building needs (training labourers for treatment process)	Monitoring requirements for Municipality	Monitoring requirements for Municipality
3	Training requirements for builders	Capacity building or training for collection & transport	Potential for private business		
4	Necessity of community awareness		Responsibility, ownership of process		

For the MCA, one has to obtain the views from many experts, and their weighting and scoring against each criterion gives a detailed evaluation of options. Either a ranking or a rating technique could be used. We used the rating technique for simplicity reasons.

The two short-listed options namely Option 1 (VIP latrine with downstream processing) and Option 2 (double vault UDD toilet with downstream processing) were compared by using MCA. All categories from Part A (toilet device) to Part E (use of the products in urban agriculture) are considered separately for each option over the entire project cycle – from construction to operation and maintenance.

The quality and reliability of the MCA depends on the knowledge and experience of the experts or stakeholders carrying out the MCA. It is best to use a high number of qualified experts or many stakeholders. Due to time constraints, we were not able to do this for this report. To illustrate the approach, we used five experts who were available to us, but clearly, the results from this MCA are only indicative and should be repeated with a more suitable group of experts.

We used the MCA data from 5 experts in the field for this analysis namely:

- Expert 1: Kalyani de Silva, MSc student at UNESCO-IHE (see de Silva, 2006)
- Expert 2: A senior lecturer in wastewater at UNESCO-IHE
- Expert 3: A lecturer in water supply and wastewater at UNESCO-IHE
- Expert 4: Manager Sewerage Services in Lusaka Water Supply and Sewerage Company, Zambia
- Expert 5: Manager Peri-urban in Lusaka Water Supply and Sewerage Company, Zambia

The following procedure was used to administer the MCA with the experts:

- First, we allocated a "default" weighting of the six main criteria mentioned above by keeping the total weight equal to 100 for each option. For the weightings, we used multiples of 5 according to the perceived importance of the criterion for the respective sanitation component (Part A to Part E). For example, on the most important criteria, we put the highest weight (clearly, this is a highly subjective assessment).
    - o The experts were allowed to change the weighting for each main criterion according to their own judgment.
    - o Then, each sub-criterion was given an equal fraction of the weight of the main criterion for reasons of simplicity.
- Scoring was done on each sub-criterion for Option 1 and Option 2 and for each sanitation component (Part A to E). The scores varied from score 1 to 5 for each sub-criterion (see Table 4-8).
- The experts did not have to judge (for scoring) the economic aspects (costs) since these were fixed based on the cost calculations (see 4.5).
- The weighted score for option was then calculated by multiplication of weight and score for each sub-criterion. The maximum total weighted score for each option would be **500** (100*5).
- The weighted score for sub-criterion by group was taken as the average weighted score of 5 experts (e.g. group weight for sub-criterion acceptability in social aspect of Part A of Option 1 = (40+33+17+33+30)/5=31).

Table 4-8: Details for scoring

Score description	Score
Excellent	5
Good	4
Acceptable	3
Poor	2
Very poor	1

4.7. Indicative results of MCA

It is obvious that the results of the MCA are highly dependent on the weightings allocated by the experts to the different aspects. This is only natural, since different stakeholders may attach different amount of importance or "weight" to the various criteria. Table 4-9 summarises the weightings that the experts assigned to the different aspect groups of the different parts of the sanitation system. From this table, the following observations can be drawn:

- The experts weighted economic aspects highest or second highest for all the parts
- Social aspects were weighted highly for Part A and E, but very low for the other parts (presumably because the user has less contact with Part B, C and D.
- Institutional aspects were rated highly for Part B and D, but low for Part A and E.
- It is noticed from individual expert analysis that the allocated weighting on the main criterion varies from 5 to 35, for example: economic aspect has weight 35 and health aspect has weight 5 for Part B from Expert 3.

Table 4-9. Weightings for different aspects for different parts (in bold the two highest weighting for each part, and cells shaded grey showing the lowest weighting for each part) – weightings are the average weightings of five experts.

Aspect group	**Weighting (average of 5 experts)**				
	Part A	**Part B**	**Part C**	**Part D**	**Part E**
Social aspects	**25**	8	5	8	**20**
Technological aspects	11	17	**27**	12	15
Economic aspects	**27**	**29**	**23**	**29**	**23**
Physical environment aspects	16	16	21	21	13
Health impacts	16	10	6	8	17
Institutional aspects	5	**20**	18	**22**	12
Total	100	100	100	100	100

The indicative summary results of MCA analysis are shown in Table 4-10 and Table 4-11. The following observations are made from the analysis:

- According to the results of individual and group analysis of data, Option 2 (double vault UDD toilet system) would appear to be more suitable than Option 1 for excreta management in AMA: The overall score for Option 2 is higher than the score for Option 1 with a significance difference.

- All experts selected Option 2 (UDD system) as the best option for Part B and Part C with significant difference with the weighted score between both options.
- For the Part A component, also it is clear that considerable difference for weighted scores can be observed from the experts, except from Expert 4 who found the Option 1 as the best option.
- There is a significant variation for the total scores for Part A to Part C and Part E from one expert to the other. However, in the case of Part D, Option 1 and 2 have marginal difference for the total score.
    - When considering the scoring for Part D, it is noticed that there is only a marginal variation of weighted scores from the experts. This is probably because the transportation of treated or sanitised faecal matter and urine from the treatment plant or storage places to the farms would not be very different for the two options.
- In the case of Part E, the views of experts are quite varied. We can observe marginal and significant differences from experts weighted scores for options for Part E.

Table 4-10: Summary of weighted scores for MCA (maximum best value for each sanitation part is 500 – in bold the better option)

Part	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Group	
	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2
Part A	339	**372**	343	**402**	277	**372**	**328**	308	279	**353**	313	**361**
Part B	293	**381**	284	**341**	243	**262**	267	**293**	220	**301**	261	**316**
Part C	249	**403**	287	**374**	231	**311**	240	**321**	187	**324**	239	**342**
Part D	**223**	217	**320**	238	138	**148**	**194**	193	130	**223**	201	204
Part E	326	**362**	285	**358**	**318**	274	255	**257**	144	**244**	266	**299**

Table 4-11: Summary of MCA analysis to assess two short-listed options for AMA (Option 1 is VIP system, Option 2 is UDD system)

	Part A	**Part B**	**Part C**	**Part D**	**Part E**	**Best option**
Expert 1	Option 2	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 2	Option 2	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 3	Option 2	Option 2	Option 2	Option 2	Option 1	Option 2
Expert 4	Option 1	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 5	Option 2	Option 2	Option 2	Option 2	Option 2	Option 2
Group	Option 2	Option 2	Option 2	Option 2	Option 2	Option 2

We observed the following difficulties while doing this particular MCA analysis:

- We filled the weight column as a default for each main criterion before distributing the analysis sheets to experts. Most of the experts then just adopted these weightings as if they were fixed.
- Time requirement for experts was high, and therefore the willingness to participate in this exercise was relatively low.
    - We could not get all experts we wanted (e.g. staff from IRC was not available).

- Experts had to have good knowledge of VIP and UDD systems and of the situation on the ground in Accra.

5. Conclusions and recommendations for further work in SWITCH work package

5.1. Conclusions

This report has demonstrated that a good concept design is needed as the basis for carrying out a multiple-criterion analysis (MCA), which implies that an MCA cannot be carried out for generic, hypothetical situations, but only for urban areas for which at least some basic information is available. The report used the case of Accra Metropolitan Assembly (AMA) in Accra (Ghana) to demonstrate the methodology proposed for carrying out a simple MCA to determine the most appropriate sanitation system (for the case study here, only excreta management was included, whereas greywater management was excluded for simplicity reasons).

The available low-cost sanitation options for excreta management in AMA were short-listed by using following selection criteria: protect groundwater and surface water sources from human excreta, low investment and operation and maintenance cost, minimise water wastage for flushing and transport of waste, odour and flies problem, and allow possibility of usage of sanitised human excreta for urban agriculture. According to these criteria, two options were short-listed: Option 1 (VIP system) and Option 2 (UDD double vault system). Option 1 does not fulfil the criterion of no potential for groundwater pollution but was included anyway because it fulfils the other criteria. Both options include downstream processing.

In the conceptual design and cost estimation process, the main components of sanitation systems were considered. They are: Part A – toilet device, Part B – collection and transport of excreta to treatment plant or storage place, Part C – treatment or storage of excreta, Part D - transport of sanitised faeces, faecal matter or urine to farm, and Part E – reuse of faecal matter and urine in urban agriculture.

The design and cost estimation were based on a population of 265,000 who are engaged in urban agriculture (approximately 16% of total population in AMA), and average household size of 4.5 considering one toilet for each household. The methodology used for cost estimating was based on similar work carried out by Mayumbelo (2006) (published in von Münch and Mayumbelo (2007)).

For Option 1 (VIP system), it was assumed that vacuum tankers are used for empting the VIP toilets once in every 5 years period and one anaerobic digester treatment plant with sludge drying beds is used to treat the faecal sludge. In the case of Option 2 (UDD system), the faecal matter is collected every 2 years and the urine is collected every 2 weeks (stored in 100 L plastic barrels). No treatment facility for faeces was considered for this option except just storage for 6 months in 3 locations spread over the area of AMA. Urine is stored for 2 weeks in a centralised storage facility and is then collected by urban agriculture farmers. Transport distances (for Part B and Part D) are approximately 10 km.

The net present value (NPV) was calculated for both options by considering 12% discount rate and 10 year project life time (MDG target in 2015). Option 1 had the lower NPV of € 10.5 million compared to Option 2 € 13.5 million. In the case of Option 2, a major cost item is the cost for the urine storage tanks.

An indicative Multi-criteria analysis (MCA) was carried out to find out the most suitable excreta management option for AMA by collecting the views from five available experts (these experts only served to illustrate the MCA, but were not specifically qualified for the Accra case). The main 6 important sustainability criteria used for the MCA were social aspects, technical aspects, economic aspects, physical environment aspects, health aspects and institutional aspects. Specific indicators were listed separately for each part of the sanitation system. The weighting of the aspects was different for each part, as decided by experts.

In accordance with the group result of the MCA, Option 2 was chosen as the best option for Part A, B, C, and E. Part D component has almost equal marks for both options. It implies that there is no significant difference in the two options with respect to transportation to farms.

Although the costs for Option 2 (UDD system - ecosan) are higher than for Option 1 (VIP - conventional), it scores higher in the MCA, where economic aspects are included as one of six aspects. Therefore, in this example, Option 2 would be more desirable for AMA.

5.2. Recommendations for further work in SWITCH work package

Recommendations for future research work based on the results of this research are as follows:

- Refine the proposed concept design further.
  - The areas where the 265,000 urban farmers are living within AMA should be further specified (identifying any clusters of urban farmers, which should first be targeted by an ecosan pilot project).
- Cost estimation should be done with accurate quantities and cost, especially for the toilet itself and the urine storage tanks since they are a major cost items.
- The MCA should be repeated with more suitable experts (e.g. relevant stakeholders such as users, farmers, municipal council staff etc.)
- A greywater management systems should be designed and included in the analysis (solid waste management could also be included; consider linkage between solid waste collection and urine barrel collection; private sector involvement).
- With regard to reuse of ecosan products:
  - Fertiliser requirements in urban agriculture of AMA should be investigated further.
  - The water holding capacity improvements for soils treated with sanitised faeces should be quantified, since it would be allow “more crops per drop” which is important given the water scarcity.
  - It is necessary to research on attitudes of Muslim people who are engaged in urban agriculture to reuse of faeces.

Proposed action items for the way forward include:

- Publish this deliverable on the SWITCH website and make it known to the Learning Alliances in the various demonstration cities.
- Include a presentation of this deliverable in the next LA meeting in Accra, check usefulness for stakeholders.

- Test the methodology proposed also in Learning Alliances of other SWITCH demonstration cities.
- Use this deliverable as input for other deliverables in Theme 4 (4.1.10, 4.1.11, and 4.1.17).

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7. Appendices

7.1. Appendix 1: Raw data for scores of two options in MCA (5 experts)

Table 7-1. Scores for Part A for Option 1 and 2 (weighted average of 5 experts)

Detailed aspects	Options score		Indicator	Explanations for lowest score
	1	**2**		
Social aspects	*77*	*82*		
Acceptability (comfort)	31	25	Qualitative	Very uncomfortable=1
Personal security (indoor versus outdoor)	15	34	Qualitative	Very insecure=1
System complexity	31	23	Qualitative	Very complex=1
Technological aspects	*32*	*41*		
System robustness (danger of pit collapsing, structural stability)	5	6	Qualitative	Low robustness=1
Robustness of use of system (effect of abuse of system)	5	3	Qualitative	Low robustness=1
Robustness against extreme conditions (flooding)	2	6	Qualitative	Low robustness=1
Use of local material for construction	6	4	Qualitative	Less material use=1
Durability/lifetime	4	5	years	Less durable =1
Flexibility/adaptability (existing ground water level, geology)	2	6	Qualitative	Less flexible=1
Potential for resource recovery (nutrients)	3	8	Qualitative	Less potential=1
Complexity for construction & O & M	5	3	Qualitative	Very complex=1
Economic aspects	*101*	*96*		
Capital cost	49	37	Cost/person	More capital cost =1
O & M cost	22	29	Cost/person/year	More O & M cost=1
Capacity to pay for user	29	29	% of annual income	More fee=1
Physical environment aspects	*41*	*66*		
Odour	9	18	Qualitative	More odour=1
Potential of groundwater contamination	9	25	Qualitative	More potential=1
Use of natural materials for construction & O&M	16	11	Type and volume/person/year	Less material use=1
Potential to devaluation of area & inconvenience to neighbourhood	6	12	Qualitative	More potential=1
Health impacts	*44*	*62*		
Potential of contact with fresh excreta	27	32	Risk assessment	More potential=1
Potential of transmit pathogens through flies	16	30	Risk assessment	More potential=1
Institutional aspects	*20*	*12*		
Skill necessity (locally) for construction and O & M	4	3	Quantitative	High necessity=1
Training requirements for users	5	3	Qualitative	High need for training=1
Training requirements for builders	5	3	Qualitative	High need for training=1
Necessity of community awareness	6	3	Qualitative	More awareness need=1
Total	314	359		

Table 7-2. Scores for Part B for Option 1 and 2 (weighted average of 5 experts)

Detailed aspects	Options score		Indicator	Explanations for lowest score
	1	**2**		
Social aspects	***19***	***25***		
Willingness of people to work in collection/transport business	8	9	Qualitative	Very low willingness=1
Reliability of collection	11	16	Qualitative	Very unreliable=1
Technological aspects	***37***	***69***		
Use of water for pumping	7	20	Qualitative	More water use=1 (pits need to have water added for Option 1)
Requirement for energy (operate pumps)	7	18	Cost/unit of energy	More energy need=1
Complexity of collection	6	13	Qualitative	Very complex=1
Access road width required	8	10	Quantitative	Less width need=1
Impact on roads and increase traffic	8	7	Quantitative	More impact=1
Economic aspects	***89***	***89***		
Capital cost	34	45	Cost/person	More capital cost =1
O & M cost	39	29	Cost/person/year	More O & M cost=1
Capacity to pay of user for collection	16	15	Cost/person (% of annual income)	More fee=1
Physical environment aspects	***28***	***51***		
Odour during collection	4	16	Qualitative	More odour=1
Noise during collection	4	15	Qualitative	More noise=1
Odour during transport	4	10	Qualitative	More odour=1
Noise during transport	9	5	Qualitative	More noise=1, Option 2 has more truck movement because of the urine barrels
Pollution from trucks (dust, CO_2 emission)	8	4	Qualitative	More pollution=1
Health aspects	***16***	***39***		
Potential health risk during collection & transport	16	39	Risk assessment	More risk=1
Institutional aspects	***74***	***47***		
Potential to private sector involvement	22	25	Quantitative	Low potential=1
Awareness amongest transport stakeholders	25	9	Quantitative	Very low existing awareness=1
Capacity building or training for collection & transport	26	13	Quantitative	Very high need for capacity building=1
Total	**263**	**320**		

Table 7-3. Scores for Part C for Option 1 and 2 (weighted average of 5 experts)

Detailed aspects	Options score		Indicator	Explanations for lowest score
	1	2		
Social aspects	***13***	***20***		
Potential devaluation of area & inconvenience to neighbourhood	6	11	Qualitative	More potential=1
Willingness of workers to work at this site	7	8	Qualitative	Less willingness=1
Technological aspects	***62***	***95***		
System robustness (risk of process failure)	9	17	Qualitative	Less robustness=1
Use of local material for construction	5	6	Qualitative	Less material use=1=1
Ease of system monitoring	4	7	Qualitative	Difficult monitoring=1
Potential for energy generation (biogas)	11	3	Cost/one unit of energy	Less potential=1
Durability/lifetime	5	5	years	Less durable=1, tarpaulin sheets for Option 2 may not last that long
Flexibility/adaptability (existing ground water level, geology)	6	14	Qualitative	Less flexible=1
Potential for resource recovery (nutrients)	6	17	Qualitative	Less potential=1
Complexity for construction & O & M	3	10	Qualitative	More complex=1
Reliability during rainy season	6	5	Qualitative	Less reliable=1, there could be leachate from faecal matter storage if not covered properly
Space requirement	9	11	Quantitative	More space=1
Economic aspects	***81***	***73***		
Capital cost	34	17	Cost/person	More capital cost =1
O & M cost	19	47	Cost/person/year	More O & M cost=1
Potential for income from biogas	28	9	Cost/one unit of energy	Less income=1
Physical environment aspects	***39***	***83***		
Potential impacts on receiving water bodies	8	26	Qualitative	More potential=1, liquids from sludge drying bed for Option 1
Potential of groundwater contamination	13	26	Qualitative	More potential=1
Odour	7	16	Qualitative	More odour=1
Noise	11	15	Qualitative	More Noise=1
Health aspects	***10***	***23***		
Potential for flies to transmit pathogens	5	11	Risk assessment	More risk=1
Potential health risks for workers	5	12	Risk assessment	More risk=1
Institutional aspects	***35***	***57***		
Resources necessity (labour, material)	9	19	Quantitative	High necessity=1
Capacity building needs (training labourers for treatment process)	9	14	Qualitative	Very high need for capacity building=1

Potential for private business	11	11	Quantitative	Low potential=1
Responsibility, ownership of process	7	12	Qualitative	High responsibility=1
Total	**239**	**350**		

Table 7-4. Scores for Part D for Option 1 and 2 (weighted average of 5 experts)

Detailed aspects	Options score		Indicator	Explanations for lowest score
	1	**2**		
Social aspects	***23***	***25***		
Reliability of collection & transport (private or Municipality)	14	15	Qualitative	Low reliability=1, Option 2 having to move urine barrels
Willingness of workers to work at this site	10	9	Qualitative	Less willingness=1
Technological aspects	***33***	***36***		
Complexity of transport	9	10	Qualitative	More complex=1
Access road width required	7	10	Quantitative	More width=1
Impact on roads and increase traffic	8	5	Qualitative	More impact=1
Requirement for specialised equipments	9	11	Quantitative	More requirement=1
Economic aspects	***13***	***3***		
Capital cost	0	0	Cost/person	More capital cost =1 (not included in cost estimate)
O & M cost	0	0	Cost/person/year	More O & M cost=1 (not included in cost estimate)
Capacity to pay for farmer for transport	13	3	Cost/person (income/person)	More payment need=1 (not included in cost estimate)
Physical environment aspects	***63***	***54***		
Odour during transport	28	28	Qualitative	More odour=1, dried faeces should not be odourous
Noise during transport	17	13	Qualitative	More noise=1, Option 2 has more truck movements because of urine barrels
Pollution from trucks (dust, CO_2 emission)	18	13	Qualitative	More pollution=1
Health aspects	***16***	***29***		
Potential health risk during transport	16	29	Risk assessment	More risk=1, dried faecal sludge from Option 1 still have more pathogens than dried faecal matter due to prolonged storage for Option 2
Institutional aspects	***56***	***57***		
Capacity building required for transport	34	36	Qualitative	More capacity=1
Monitoring requirements for Municipality	22	21	Qualitative	Difficult to monitor=1
Total	**204**	**204**		

Table 7-5. Scores for Part E for Option 1 and 2 (weighted average of 5 experts)

Detailed aspects	Options score		Indicator	Explanations for lowest score
	1	**2**		
Social aspects	***58***	***50***		
Potential for cultural barriers to use products	31	23	Qualitative	More potential for barrier=1
Farmers willingness to utilise the fertiliser	27	27	Qualitative	Less willingness=1
Technological aspects	***38***	***52***		
Potential for impurities in final products grown with that fertiliser	8	11	Qualitative	More potential for impurities=1, Option 1 faecal sludge may contain more contaminants
Ease of storage of fertiliser (for farmers)	11	10	Qualitative	Difficult storage=1, need to store urine fertiliser
Quality of fertiliser or soil conditioner	7	21	Qualitative	Low quality=1
Ease of application of fertiliser (need for new machinery)	12	11	Qualitative	Difficult to apply=1, urine application is different
Economic aspects	***40***	***65***		
capital cost	0	0	Cost/person	Not estimated, Option 2 probably higher due to urine storage
Lower expenses for not having to buy chemical fertiliser	15	28	Cost/person	Higher expenses=1, amount of fertiliser from Option 2 is much higher than for Option 1
Income from higher yield by fertiliser use	24	37	income/person	Low income=1
Physical environment aspects	***45***	***38***		
Odour during storage of urine at farm	11	6	Qualitative	More odour=1, Option 1 no urine is applied
Odour during application of urine at farm	11	7	Qualitative	More odour=1
Odour during storage of solids at farm	9	11	Qualitative	More odour=1
Odour during application of solids at farm	8	10	Qualitative	More odour-1
Risk of over-fertilisation and resulting run-off	6	4	Qualitative	High risk=1
Health aspects	***47***	***66***		
Potential health risks for consumers of fertilised foods	27	36	Risk assessment	High risk=1
Potential health risk during handling of fertilisers for farmers	20	29	Risk assessment	High risk=1, Option 1 remaining pathogens
Institutional aspects	***37***	***30***		

Capacity building requirements for farmers	26	21	Qualitative	More capacity building required=1
Monitoring requirements for Municipality	12	9	Qualitative	Difficult to monitor=1
Total	**265**	**302**		

7.2. Appendix 2: Costing data (used for calculating NPV values)

Table 7-6: Input data for cost calculation (those values in bold are different than in von Münch and Mayumbelo (2007))

Parameter	Symbol	Unit	Option 1	Option 2	Further explanations
Cost of using a transport vehicle for transport from household to treatment site (Part B)	$C_{t,1}$	€/event	**70**	**50**	Travel distance about 10 km (current practice in Accra) - Vacuum tanker for Option 1 & open truck for Option 2
Cost of vault emptying, per event	C_{ve}	€/event	0	5	Assuming 30 minutes, and € 10 per hour salary cost
Cost of treating faecal sludge	$C_{tr,s}$	€/m^3	2.4	0	Based on current charge of AMA
Sales prices for treated faecal matter	C_{Fm}	€/ton	2	2	Current price for biosolids from AMA
Sales price for urine	C_{urine}	€/m^3	0	0.75	Personal communication Linus Dagerskog, CREPA, Burkina Faso (nutrients worth 15 cents per 20 L jerry can; able to sell at one tenth of this price)
Annual cost of a general worker	$C_{w,a}$	€/a	0	**2,000**	
Frequency of desludging or emptying	F_d	1/a	0.2	**0.5**	Desludging period 5 years for Option 1 and emptying period for Option 2 is 2 years
Factor to account for volume change	$F_{w,1}$	-	2	0.5	Option 1: Increase due to necessary water jetting.
Factor to account for water loss during treatment in Part C	$F_{w,2}$	-	**0.2**	0.5	Option 1: Own estimate for dried fraction from drying beds, Option 2: further drying ($F_{w,1}$ x $F_{w,2}$ = 0.25)
Average number of people per toilet	$N_{P/t}$	-	**4.5**	**4.5**	Equals to average household size (one toilet per household)
Number of people covered in the scheme	N_{Accra}	cap	**265,000**	**265,00**	Design value (urban population in AMA who engage in urban agriculture)
Number of workers at the storage site	N_w	-	0	5	Design value
Specific annual faecal sludge/matter production	p_f	m^3/cap/yr	0.07	0.05	Heinss *et al.* (1998) for Option 1; Jönsson *et al.* (2004) for Option 2
Specific annual urine production	p_{urine}	m^3/cap/yr	0	0.55	Source: Münch (2007)
Density of compost or dried faecal matter	ρ	ton/m^3	1.2	1.2	Estimate
Time between desludging or emptying events	T_d	years	5	**2**	Design value (inverse of F_d)
Total volume of substructure	$V_{sub,min}$	m^3	**2.475**	**0.45**	Equals sludge volume when pit or vault is full (see Table 5-2)
Volume of transport vehicle (vacuum tanker for Option 1, skip on open truck for Option 2)	V_{tv}	m^3	5	15	

Table 7-7: Investment cost for Option 1 and Option 2 for AMA (in € unless otherwise indicated)

Part		Option 1 (VIP system)	Option 2 (UDD system)	Comments
Part A	**Investment costs of latrine**	6,261,328	7,903,916	Cost of one toilet
Part B	**Transport cost from latrine to treatment plant**	440,000	400,000	4 vacuum trucks of € 110,000 each for Option 1; 8 (1 urine transport and 7 for faeces transport) open trucks of € 50,000 each for Option 2
Part C	Treatment plant (bio gas digester + sludge drying beds)	205,000	0	See Appendix 9
	Land requirement (value) for treatment plant	153,990	0	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Faecal matter storage	0	29,117	See Appendix 9
	Land requirement (value) for faeces storage	0	48,140	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Urine storage tanks	0	1,925,882	See Appendix 9
	Land requirement (value) for Urine storage	0	81,490	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Subtotal	***358,990***	***2,084,629***	
Part D	**Trucks to transport the waste and urine**	0	0	Assume farmers have to get it
Part E	**Sale of treated sludge or faecal matter**	0	0	No capital cost item here
	Total investment costs (million €)	**7.1**	**10.4**	
	Total investment costs (€/cap)	**27**	**39**	Total investment cost divided by number of people covered in scheme (265,000)

Table 7-8: Annual Operation and maintenance cost for Option 1 (VIP system) and Option 2 (UDD system) in €/year unless otherwise indicated

Description		Option 1	Option 2	Comments
Part A	Operation & Maintenance costs for toilets	0	0	Structures are robust enough requiring only cleaning
	Material added after defecation (sand)	0	0	free
	Subtotal	0	*0*	
Part B	Cost of removing sludge or faecal matter from the pit or vault	0	147,222	First part of Equation 2
	Faecal sludge / faecal matter transport cost from plot to treatment plant / storage site	519,400	22,083	Second part of Equation 2
	Urine barrel transport costs from plot to storage site	0	485,833	Third part of Equation 2
	Subtotal	*519,400*	*655,139*	
Part C	Treatment costs (including labour)	89,040	0	First part of Equation 3
	Staff labour cost for storage facility	0	10,000	Second part of Equation 3
	Subtotal	*89,040*	*10,000*	
Part D	Transport cost of treated sludge or faecal matter from treatment plant to disposal/user	0	0	Assumed that transport costs are covered by farmers when they come to buy fertiliser
Part E	Income from sale of treated sludge or faecal matter	-17,808	-7,950	First part of Equation 4 (note negative values since it is an income)
	Income from sale of urine	0	-109,313	Second part of Equation 4
	Subtotal	*-17,808*	*-117,263*	
Total O&M cost (million €/yr)		0.59	0.55	
Total O&M cost per capita (€/cap/yr)		2.2	2.1	