Exploring the feasibility of integrated sanitation systems for Uganda

Dissertation

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by

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To the one who sits on the throne. EKA DEKE IBUSAKINIT IIMA IJO

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Abstract

In Africa alone, urbanisation in projected to constitute at least 60% of the overall population by 2050. The urbanisation trend in Uganda is no different from that of Africa where urbanisation is projected to increase from 17% in 2016 to at least 33% in 2050 (Maseland and Kayani 2010; UN 2014b). Such rapid urbanisation will exert pressure on public services and infrastructure which may not be developed at a similar rate as population increase. Current trends already show that low-income countries, especially in Sub-Saharan Africa have limited public services in key areas of health care, education, sanitation and housing among others, This implies that planned action for provision of environmental sanitation services among other services should be considered if the projected increase in urbanisation in Uganda is to yield economic development.

The integrated sanitation system approach proposed in this dissertation is based on the concept of environmental sanitation and it considers combined management of organic waste streams such as faecal matter, organic solid waste and wastewater effluent. The integrated sanitation system approach, which additionally emphasises resource recovery from organic waste management, is considered a possible solution to organic waste management challenges faced in peri-urban and urban settings within Uganda.

With reference to environmental sanitation in urban areas, approaches and corresponding planning frameworks have been developed. Although some of the planning frameworks suggest that technical, institutional, financial and social-assessments should be carried out for the sanitation technology options, a systematic way to accomplish these evaluations is not included. Furthermore, there is no reference to the meaning of sustainable technology options with reference to a particular context. Moreover, a procedure for an inclusive assessment of the sustainability of different sanitation technology options is abscent, despite the fact that most of these environmental sanitation approaches were based on the Bellagio principles of sustainable sanitation

Therefore, this research uses a combination of methods to fill the gaps identified in some of the existing environmental sanitation approaches. This task is accomplished in four phases; the initiation phase, holistic feasibility assessment, sustainability assessment and development of a planning framework for the integrated sanitation system approach. Moreover, supporting tools not limited to observation and questionnaires were used to enable the research. In addition, interaction with stakeholders from various professional backgrounds throughout the research phases was carried out. To accomplish the various tasks within the phases of the research, a case study approach was considered and Uganda Christian University (**UCU**) was selected as a case study area.

UCU is a private University, which experiences challenges in managing organic waste streams such as sewage sludge from an activated sludge treatment plant. However, **UCU** is interested in ensuring sustainable sanitation by managing organic waste streams generated from the University while recovering resources in the form of biogas. After the in-depth case study, generalisation of the findings was carried out to include peri-urban and urban areas in Uganda with similar challenges and opportunities to **UCU**.

The results of this research indicated that integrated sanitation systems are both feasible and sustainable. Moreover, a planning framework for the integrated sanitation system approach was suggested and it consists of 8 steps; (1) process initiation and demand creation, (2) launch of planning process, (3) assessment of current situation and prioritisation of problems, (4) identification of system alternatives and feasibility assessment, (5) sustainability assessment of alternatives, (6) application of demonstration units, (7) implementation, (8) monitoring and evaluation.

It can be concluded that four key elements are required to enable planning of an integrated sanitation system. These key elements include; context assessment, holistic feasibility assessment of sanitation system alternatives, sustainability assessment of sanitation system alternatives, and the inclusion of a participatory approach. This research provides a theoretical and practical basis for consideration of integrated sanitation systems as a possible solution for the management of organic waste streams generated from urban areas in Uganda, with the possibility of consideration in areas within Sub-Saharan Africa. The approach which additionally emphasises resources recovery from the management of organic waste highlights a sanitation-energy-agriculture nexus, offering a more attractive stance with regards to sanitation management in urban areas of Uganda.

Keywords: Integrated sanitation systems, feasibility assessments, sustainability assessments.

List of Acronyms

AD	Anaerobic Digestion
BMP	Bio-Methane Potential
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CSTR	Continuous Stirred Tank Reactor
FUAS	Flensburg University of Applied Sciences
FU	Functional Unit
GHG	Greenhouse Gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IWRM	Integrated Water Resources Management
LCA	Life Cycle Assessment
MCDA	Multi-Criteria Decision Analysis
MSW	Municipal Solid Waste
NEMA	National Environment Management Authority
NWSC	National Water and Sewerage Corporation
UCU	Uganda Christian University
UECCC	Uganda Energy Credit Capitalisation Company
VAT	Value Added Tax
WFP	Water for the People
WWTP	Waste Water Treatment Plant

List of Units

Unit	Description
%	Percentage
d	day
h	Hour
kg	Kilogram
kWh	Kilowatt hour
l	Litre
m	Metre
m^2	Square metre
m^3	Cubic metre
ton	Tons
TS	Total Solids
oTS	Organic Total Solids

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1 Introduction

Chapter 1 *discusses the underlying problems on regional-and local scales which motivate the proposal of an integrated sanitation system approach as a possible solution for organic waste management in urban areas in Uganda. The regional scale in this context refers to Sub-Saharan Africa while the local scale refers to Uganda. This Chapter also outlines the research goal, scope and the structure of the dissertation.*

1.1 Background: Global Importance of Sanitation

Described as interventions that ensure improved management of human excreta through safe disposal or re-use, sanitation is considered one the most serious problems facing humankind in today's world (WSSCC and WHO 2005; Seetharam 2015). Poor sanitation affects human health, it also results in pollution of water resources and has economic impacts as well (Lüthi et al. 2011a). Global statistics show that poor sanitation causes at least 280,000 diarrhoea-related deaths in low and middle income countries. While for every US dollar invested in sanitation, there is a return of US$5.50 in lower health costs in addition to more productivity and fewer premature deaths (WHO 2012).

The importance of sanitation has been further bolstered by global initiatives set up by the United Nations under the auspices of Millennium Development Goal[1] (**MDG**) 7. Target 7C of this goal called for *halving of the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 (UN 2014a)*. During the **MDG** era 1990-2015, global access to improved sanitation increased and this enabled 2.1billion people have access to improved sanitation. During this time the use of improved sanitation facilities is estimated to have risen from 54 % to 68 % globally as indicated in Figure 1-1. Despite the registered progress, the global **MDG** target of achieving 77 % access to improved sanitation was missed by 9 %. This shortfall implied that nearly 700 million people did not have access to improved sanitation. Veering away from the **MDG** target set, World health Organisation (WHO) facts further indicate that about 2.4billion people still do not have access to basic sanitation facilities (WHO 2016).

Notwithstanding the shortfalls in attaining improved sanitation globally, large disparities still exist between developed and developing countries with nearly all the developed countries achieving universal access. Meanwhile, wide variations in sanitation coverage are registered in developing countries, with nations in Sub-Saharan Africa and Southern Asia registering the lowest coverage as shown in Figure 1-1 (UNICEF and WHO 2015). Undoubtedly, these alarming figures and facts represent the "unfinished business" from the **MDG** era, which has been carried forward to the Sustainability Development Goal (**SDG**) era i.e. 2015-2030 duration. The 17 **SDGs** adopted in 2015 seek to build on the **MDGs** and complete what was not achieved in the **MDG** era.

[1] MDG;The world`s time- bound and quantified targets for addressing pervert in various dimensions (UN 2014b).

Furthermore, the **SDGs** seek to realise human rights for all and achieve gender equality in addition to empowerment of all women and girls (UN 2015). The dedication of an entire goal to water and sanitation instead of a target as was the case for **MDGs** further reflects the level of importance attached to the respective themes. **SDG 6** which seeks to *ensure availability and sustainable management of water and sanitation* has seven targets, two of which focus on accomplishing the unfinished **MDG** agenda on sanitation. Target 6.2 focuses on *achieving adequate and equitable sanitation and hygiene for all* while target 6.3 seeks to improve water quality by considering the whole chain (Hossain 2015; UN 2015).

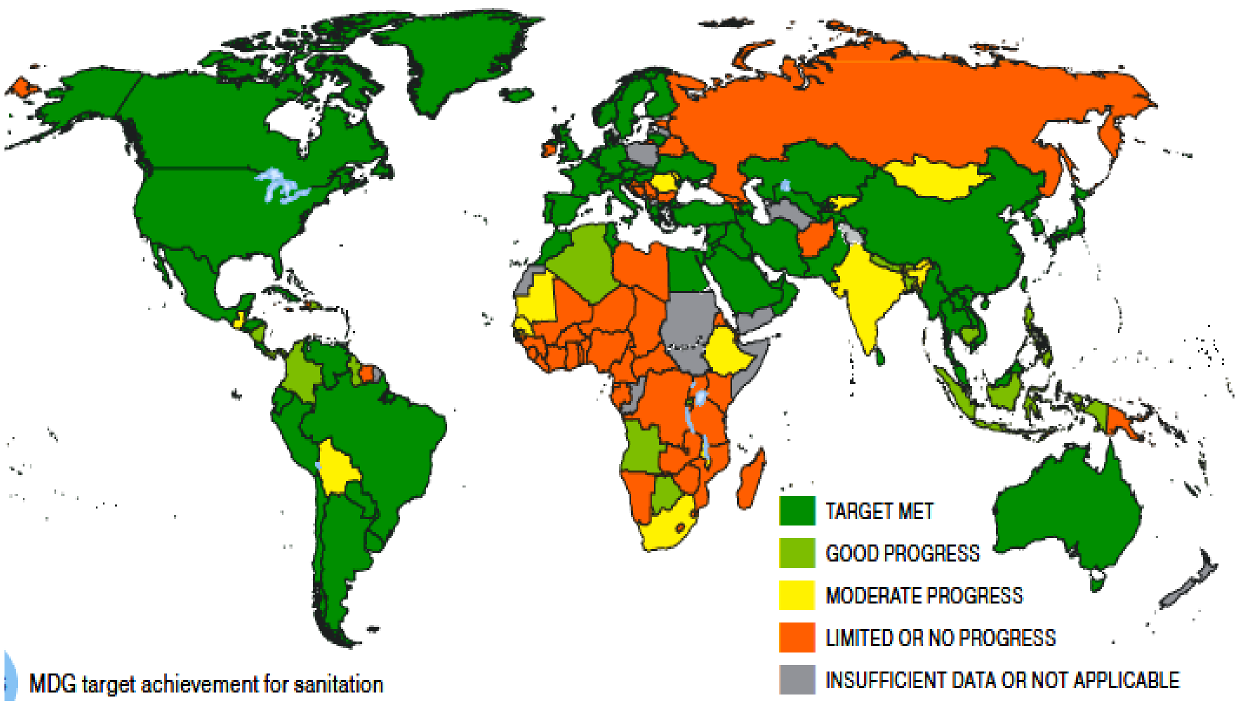

Figure 1-1: Sanitation coverage achievement in MDG era
Source: (UNICEF, WHO 2015)

1.2 Regional and Local Sanitation Situation

Statistics on sanitation coverage in Sub-Saharan Africa during the **MDG** era indicated a measly 20% achievement in comparison to 32% registered for Southern Asia. These figures emphasise the dire need for countries in Sub-Saharan Africa to increase sanitation coverage (UNICEF and WHO 2015). In Uganda, reports on sanitation coverage until 2015 are quite conflicting with districts reporting different figures from different sources. However, findings from the WHO/UNICEF[2] Joint Monitoring Programme (JMP) indicated that only 35% of the rural population had access to improved sanitation in comparison to 34% of the urban population during the **MDG** era.

[2] UNICEF: United Nations Children's Fund
WHO: World Health Organization

The low figure for improved sanitation access in urban areas was attributed to the fact that half the urban population shared improved sanitation services (MoWE 2015). Evidently, the low trend of improved sanitation access in Uganda does not vary much from the regional trend where a 20% achievement in improved sanitation access was attained during the **MDG** era. These disturbing facts regarding sanitation coverage in Sub-Saharan Africa are further brought to the spotlight by projected future population increase in Africa and specifically Uganda. Projections are that Africa's population size is likely to double to almost two billion people by 2050 while Asia and Latin American population will probably increase by about 20 %. The projected population increase will influence urbanisation, resulting in an urban population of about 1.23 billion people which represents at least 60% of the overall population (Sippel 2011; Maseland and Kayani 2010). Regionally, Uganda has followed this trend since 2016, registering a population of at least 40million and is projected to increase to at-least 100million by 2050. Uganda with a high population growth rate of 3.24% and one of the highest growth rates in the world, recorded an urbanization rate of 17% in 2016. This is projected to increase to 33% in 2050 (Haub and Gribble 2011).

Globally, experiences show that urbanisation has been associated with improved human development, rising incomes and better standards of living. Such benefits can be accrued when well devised public policies and structures are in place. These components steer demographic growth and convert urban accumulation of activities and resources into healthy economies which in turn boost equitable wealth distribution. However, such a trend is not seen in Africa where the related discourse shows that urbanization in Africa has not generated significant formal economic development. Instead 63% of Africa`s urban population still lives in slums characterised by overcrowding, inadequate housing, insecure tenure and lack of access to water and sanitation (UNECA 2013). Even though high population densities in urban areas could be a motivating factor for better service provision, the fact that most African nations still grapple with provision of basic services is a limiting factor. As such, increasing human density, especially in urban areas which also corresponds to increased quantities of waste could imply that in excessive amounts, environmental degradation, water pollution and other related health and livelihood impacts would result (Lüthi et al. 2011b; Cross and Coombes 2014).

Furthermore, a unique feature in the urban African setting is the presence of low income, informal and illegal settlements, and Uganda is no exception. It is estimated that 150 to 180 million urban dwellers in Africa who are mostly living in rapidly growing informal settlements lack sanitation. Part of the reason for such alarming facts is that most of the urban dwellers do not own land and/or houses and thus, lack incentives to invest in sanitation (AMCOW 2011; Cross and Coombes 2014). The implications of such gloomy realities is that there is need for both access to and the quality of sanitation to increase at a much faster pace and on a larger scale than in the past to meet this continuously growing demand in urban areas.

While increasing the quality and access to sanitation in urban areas is crucial, understanding of the disparities between the rich and poor could inform the process. Noteworthy is that there are major disparities in access to sanitation in urban areas between the rich and the poor. Disaggregated data shows that in Sub-Saharan Africa, the lowest wealth quintile had only 42 % access to improved sanitation compared to 91 % for the richest quintile between 2004 and 2009. Such disparities illuminate the pressing need to address the urban sanitation challenge comprehensively while including slum dwellers and poor communities that have often been neglected (Hawkins et al. 2013; Peal et al. 2010; Cross, and Coombes 2014). An all -inclusive sanitation model which captures all segments of urban settlements could contribute to reducing the disparity in sanitation coverage in urban areas. Already experiences by various donor organizations such as BMZ, DFID,UNDP[3] affirm that all-inclusive sanitation models which promote an "integrative" way of thinking, especially in planning and implementing of water and sanitation projects should be considered(BMZ 2009; Watkins 2006). In this context, the "integrative" way of thinking draws from the integrated water resource management[4] (IWRM) concept which encourages the inclusion of water and sanitation related issues in the political agenda of implementing countries (Hassing et al. 2009).

Generally, the responsibility for sanitation in developing countries including Uganda is shared by multiple institutions i.e. health, infrastructure, environment, education, local government. Although reforms in these sectors have been considered or are being implemented, fragmentation of institutional responsibility still exits and slows down the process of sanitation management (Tiberghien et al. 2011; BMZ 2009). Fragmentation in sanitation is characterised by separate handling of knowledge and promotion of political mandates in various institutions implementing sanitation issues. Fragmentation in sanitation has negative impacts some of which include; inefficient distribution of financial and human resources, poor coordination and unnecessary conflict within government ministries or organisations (WaterAid 2011; Ekane et al. 2016).

Moreover, the conventional approach to sanitation in most of these countries still involves separate management of waste streams and at times there is no contact between the different entities providing the sanitation services. For instance in most urban centres in Uganda, solid waste management basically includes collection of the waste which is composed of at least 70% organic material, transportation of the waste and dumping it in landfills.

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[3] BMZ:Federal Ministry of Economic Cooperation & Development, Germany
DFID:Department of International Development, United Kingdom
UNDP:United Nations Development Programme

[4] IWRM; "seeks to promote coordinated development and management of water, land and related resources, maximizing the resultant economic and social welfare without compromising the sustainability of vital ecosystems (Hassing et al. 2009

In main cities particularly parts of Kampala, less than 10% of the wastewater generated is collected by sewer systems and treated in centralised treatment plants. While mostly onsite sanitation systems are used to manage wastewater from areas not connected to main sewer systems (MoWE 2016; Schoebitz et al. 2016). With reference to such a background, challenges associated with fragmentation in sanitation already mentioned can be expected. Moreover, the conventional approach to sanitation characterised by linear waste management systems where valuable plant nutrients are often wasted and create pollution problems are still the "norm" (Schertenleib et al. 2004).

By implementing an all-inclusive "integrative" sanitation approach, coordination between different actors and resource recovery from waste can be achieved. This would imply impacts from fragmentation of sanitation could be reduced while promotion of a closed nutrient loop approach is additionally achieved. Therefore, with reference to the miserable statistics regarding sanitation access in urban areas, projected increase in urbanisation in addition to the related impacts of sanitation fragmentation, an opportunity exists for a sanitation approach which could fill some of the identified gaps. This research suggests that an integrated sanitation system approach could be a viable option for the management of organic waste streams within urban areas in Uganda.

1.3 Integrated Sanitation System Approach

Sanitation has often been referred to as interventions that improve the management of excreta with the aim of interrupting the disease cycle while providing a safe and hygienic environment. This definition which limits sanitation to treatment and disposal of faeces and urine has evolved over time with the realisation that the scope of sanitation is much broader and may include other "soft" components. Some of these soft components include policies, legal and management frameworks, political will and investments (WaterAid 2011; Peal et al. 2010). Furthermore, the realisation that components like solid waste, sullage and drainage can no longer be isolated has further contributed to the coining of concepts such as environmental sanitation. This concept considers a range of interventions designed to improve the management of excreta, sullage, drainage and solid waste. The scope of environmental sanitation is even widened for developing countries by further consideration of vector control (WELL 1998; WSSCC and WHO 2005).

To ensure effective sanitation provision based on the wide scope of environmental sanitation, interaction across various sectors which include; economy, health, environmental protection and socio-cultural sectors is important. Despite the "all-inclusive" scope of environmental sanitation and it`s attempted implementation at household and community level in developing countries, Lüthi and Parkinson (2011c) point out that there is limited systematic evaluation of system options, especially in regard to finance and institutional requirements (Lüthi and Parkinson 2011c). Moreover, in most cases, implementation of sanitation is achieved in a fragmented manner where separate handling of the various components is carried out. In the worst case scenario certain components maybe neglected (Lüthi and Parkinson 2011c; Kemper, Widstrand 1991).

The integrated sanitation system approach proposed in this research is broached from the environmental sanitation concept. An integrated sanitation system approach considers interventions designed for improved management of organic solid waste, sewage and faecal sludge, animal dung and wastewater effluent reuse. Furthermore, the approach considers sustainable sanitation aspects reflected through the system objective of resource recovery in the form of biogas and organic fertilizer. As such, the integrated sanitation system approach highlights a sanitation-energy-agriculture nexus and embraces three key dimensions which include; multi sector/stakeholder involvement, sanitation system elements and components as well as the holistic nature of sanitation. The three dimensions share some similarity with those stipulated in integrated sustainable waste management although the whole concept of integrated sanitation can be traced back to Integrated Water Resources Management(IWRM)(Hassing et al. 2009; Klundert and Anschütz 2001-; Hassing et al. 2009).

Resource recovery from sanitation is not necessarily a new phenomenon in developing countries such as Uganda since success stories of **EcoSa**n[5] systems and bio-latrines already exist. Application of **EcoSan** for combined excreta and solid waste management has been cited as having the potential to contribute to integrated excreta and solid waste management. Both **EcoSan** and bio-latrines prevent pollution by sanitising urine and faeces in addition to recovering nutrients which may be used in agriculture. Bio-latrines additionally recover biogas which is used as a source of energy(Haq and Cambridge 2012; UNICEF 2014).

In Europe and other developed nations, a common example of an integrated sanitation system includes wastewater treatment plants, where anaerobic digestion of sewage sludge and other organic waste streams is promoted, resulting in nutrient and energy recovery. Biogas produced from the anaerobic digestion process is used to generate energy, supplementing own energy demand within the plant. Meanwhile, the digestate from the anaerobic digestion process is used as organic fertilizer in the absence of contamination restrictions (Al Seadi et al. 2008). In spite of the examples of integrated sanitation approaches mentioned, it would suffice to say that the approach has not fully been exploited, particularly in Uganda since existing examples are still limited to **EcoSan** and bio-latrines, commonly used in residential and community establishments. It is against such a background that the integrated sanitation system approach proposed in this research is considered as a possible solution to management of organic waste streams generated from urban and peri-urban areas in Uganda.

Although the integrated sanitation system approach may appear attractive, potential challenges related to multi sector and multi stakeholder requirements through the value chain can be anticipated. Engagement and management difficulties are anticipated when dealing with multiple sectors and stakeholders.

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[5]Ecological sanitation(EcoSan); implies separating waste streams, saving water and energy, nutrient recycling, cost efficiency, and the integration of technology to environmental, organizational and social conditions Jenssen et al. 2004,p.6

Additionally, difficulties in establishing an enabling environment which would be defined by a broader scope of policies, standards and plans to be considered can also be expected (UNEP 2012). Moreover, since combined management of organic waste streams are proposed, a combination of processes/technologies can be expected within the integrated sanitation systems. As such, the absence of well-defined criteria or procedure for the assessment of integrated sanitation systems would imply that selection of the most appropriate system for a particular context would be challenging task. If not dealt with, all these potential challenges could stifle the planning and implementation of integrated sanitation systems. Therefore, it is against such background and that this research was inspired.

This research aims to explore the feasibility of integrated sanitation systems for urban areas in Uganda and adopts a case study approach to inform the research. Uganda Christian University (**UCU**) in Uganda is selected the case study area. The institution offers a wealth of insight on challenges and opportunities of such a sanitation system while additionally providing a platform where new ideas can be discussed and tested.

1.4 Background of Problem at Case Study Level

The **UCU** campus considered is located in Mukono Municipality, about 22km from Kampala the capital city of Uganda. The University whose population is estimated to be about 6,000 manages the waste generated in various ways. **UCU** has an onsite activated sludge wastewater treatment plant (**WWTP)** which treats all wastewater generated from the University. The **WWTP** which has a capacity of 320 m^3/day currently treats only 160m^3/day of wastewater, generating effluent and sewage sludge. The sewage sludge generated is dewatered in a 15m^3 settling tank before being directed to a 30m^2 lagoon where the sewage sludge is left to stabilise over a duration of one year. About 30% of the sewage sludge from the lagoon is then used as soil conditioner by interested local farmers neighbouring the University, while a portion of the soil conditioner is also applied on **UCU** sports field. The residual 70% sewage sludge is left in the lagoon, posing a disposal challenge to the University. The treated wastewater effluent on the other hand is directed to drainage trenches before eventually being drained into the environment.

Alternately, solid waste generated from **UCU** is managed in different ways. Plastic containers are sorted and taken for recycling by a private service provider. Kitchen waste comprising of food waste and peelings is collected by interested local farmers and used as animal feed. While other non-biodegradable waste is either incinerated within **UCU** or collected for disposal at Mukono Municipal landfill, located about 7km from the University.

UCU also owns a farm located at Ntawo about 3.5km from the main campus. This farm has been leased to a private operator who takes care of at least 95 Friesian cattle. A portion of the cow dung from the animal shelter is collected by local farmers and used as soil conditioner in neighbouring gardens. While most of the cow dung is dumped in an animal enclosure or kraal where the animals rest during the day.

The University is also currently highly dependent on firewood to supply its cooking energy demand and this accounts for over 90% utilisation. While charcoal and electricity utilisation only accounts for 8% and 2% cooking energy demand respectively. Regarding other energy needs, **UCU** relies on electricity supplied from the national grid as well as diesel-run backup generators to meet demand. According to the University`s Strategic Plan for the duration 2012-2018, **UCU** is interested in shifting from dependence on firewood to meet cooking demands by utilising cleaner energy sources such as biogas. Moreover, the University proposes utilisation of organic waste like sewage sludge from the **WWTP** for energy recovery. Therefore, with reference to the University`s background described, this research is interested in *exploring the feasibility of an integrated sanitation system for **UCU** as a case study area*. The proposed integrated sanitation system considers co-management of organic waste streams generated from the University, which include sewage sludge, kitchen waste and cow dung with the option of reusing effluent from the **WWTP**. In addition, management of faecal sludge from the University pit latrine and neighbouring areas of Mukono Municipality is considered.

The additional management of faecal sludge from neighbouring areas of Mukono Municipality is inspired by the lack of a faecal sludge treatment plant in Mukono Municipality and fact that currently the **WWTP** at **UCU** operates at half its capacity. Mukono being one of the towns without access to National Water and Sewerage Corporation (NWSC) sewer network implies that onsite sanitary facilities, which may include pour/ flash toilets connected to septic tanks and pit latrines are mainly used. These facilities will eventually require emptying of sewage and faecal matter, which is often the responsibility of respective households, institutions and entities (Kanathigoda 2014; MoWE 2015).

The absence of a faecal sludge treatment plant in Mukono Municipality means that in case sewage or faecal sludge is evacuated using cesspool emptiers or other measures, it has to be transported to the nearest faecal sludge treatment plants which are located in Kampala, 22km away. Increased costs due to long distances for transportation of the faecal matter would then be incurred by the customers and this can be a discouraging factor. Such hiccups can also lead to illegal dumping of faecal sludge, which in turn poses a threat to public health. In the worst case scenarios, abandoning of filled up latrines or total negligence towards on-site sanitary facilities may be practiced, resulting in overflowing faecal matter in to the environment. Therefore, the option to additionally manage a portion of the faecal sludge from Mukono Municipality at the **UCU** plant would lighten the burden on interested customers.

Management of organic waste streams from **UCU** and Mukono Municipality may therefore be carried out using various treatment/management options not limited to composting, incineration, solar drying and anaerobic digestion. The proposed integrated sanitation system approach for **UCU** considers the application of anaerobic digestion in combination with other treatment options to manage the organic waste streams and reuse effluent from the **WWTP**.

Evidently, anaerobic co-digestion of organic waste streams resulting in resource recovery is a mature technology as justified by its continuous application globally (Gonzalez et al. 2010). By combining anaerobic digestion with other treatment options, the integrated sanitation system proposed would ensure improved sanitation while additionally recovering resources in the form of biogas and organic fertilizer. Figure 1-2 shows the sources of organic waste and firewood which is the main source of cooking energy at **UCU.**

WWTP-source of sewage sludge at **UCU**

Food waste from **UCU** kitchen

UCU holding farm-source of cow dung

Firewood used for cooking purposes at **UCU**

Figure 1-2: Organic waste stream sources and dominant cooking energy source at UCU
Source: Author

1.5 Justification of Research

With reference to **UCU**, the current sanitation system exposes a gap in management of sewage sludge. After partial stabilisation in the lagoons for a duration of one year, final disposal of at least 70% of the sewage sludge is still a major challenge. Given that the disposal of sewage sludge in landfills is prohibited by law in Uganda, further management of the sludge could be achieved by transporting it to designated centralised treatments plants (KCCA 1997).

The nearest treatment plants where such services could be offered are located in Kampala (**NWSC** Lubigi and Bugolobi) atleast 22km away. Although transportation of the sewage sludge to these plants could be a possibility, logistical, aesthetics and cost requirement associated with this possibility could be a major demotivating factor. On the contrary, identification of measures for further management of sewage sludge at **UCU** while additionally recovering resources in the form of biogas and organic fertilizer could be an attractive solution. Moreover, with the possibility to further manage sewage sludge at **UCU**, opportunities to assist in management of faecal sludge collected from Mukono Municipality could exist. Basing on the fact the **WWTP** at **UCU** operates at half capacity, further management of faecal sludge which is currently a challenge in Mukono Municipality could be considered.

Currently, the organic waste from the University kitchen is taken freely by local farmers and used as animal feed. In case an integrated sanitation system is considered for **UCU**, the University could additionally benefit from the kitchen waste as a substrate for the anaerobic digestion process. Amicable understanding with local farmers currently utilising kitchen waste would be necessary to avoid any unintended consequences. By utilising the kitchen waste as substrate, a shift from considering the kitchen waste as a nuisance (conventional approach) to a closed loop approach where resources are recovered from the waste could result.

The integrated sanitation system approach proposed also considers reuse of wastewater effluent from the **WWTP** as process water for the anaerobic digestion process. In so doing, the fresh water footprint associated with anaerobic digestion application could be reduced. This is especially significant in developing countries where obtaining continuous flow of fresh water could be a challenge and is costly. Generally, since the integrated sanitation system approach proposed considers sanitation improvement while additionally recovering resources in the form of biogas and nutrients from organic fertilizer, the approach is considered attractive. A sanitation–energy-agriculture nexus can be traced in case an integrated sanitation system approach is considered (Parkinson et al. 2014; Hu et al. 2016). Utilisation of the recovered resources would imply reduction in expenses on artificial fertilizer for local farmers and reduction of expenses incurred in purchasing firewood for **UCU**.

Moreover, consideration of the integrated sanitation system approach could also imply that limitations associated with separate management of organic waste streams mentioned earlier could be avoided. By adopting a holistic approach, the multi sector and actor involvement associated with integrated sanitation systems could be catered for, offering solutions to the separate sanitation management and fragmentation dilemmas. In terms of applicability, the integrated sanitation system approach is considered for community as well as town or city domains. As such, the approach could be considered for schools, institutions of higher learning, development and or housing estates, towns and cities.

The integrated sanitation system approach could be a solution to organic waste management challenges experienced in the mentioned urban and peri-urban settings in Uganda, with the possibility of application in similar areas within Sub -Saharan Africa. With reference to the identified potential for application of the integrated sanitation system approach in Uganda, this research explores the feasibility of the sanitation systems and goes ahead to assess their sustainability, taking into consideration **UCU** as a case study to inform the research. The outcome from the feasibility and sustainability assessment of the integrated sanitation systems is expected to further inform the development of a planning framework for the approach. This additional step is expected to simplify planning and possible implementation of integrated sanitation system in various urban settings in Uganda and beyond. Already, various frameworks and decision tools have been developed to guide planning and implementation of various sanitation approaches, including urban environmental sanitation (EAWAG-SANDEC 2005; Lüthi et al. 2011a; WaterAid 2011). Nevertheless, developing a planning framework specific for the integrated sanitation system approach would be important since the approach considers management specific waste streams and incorporates a holistic perspective.

1.6 Objectives of Study

The overall goal of this research is to explore the feasibility of an integrated sanitation system approach for urban areas in Uganda. The specific objectives of the research are:

1. To explore the technical, environmental, socio-cultural and economic feasibility of integrated sanitation systems for urban areas in Uganda, considering Uganda Christian University as a case study.

2. To assess the sustainability of integrated sanitation systems for urban areas in Uganda.

3. To contribute to the development of a planning framework for an integrated sanitation system approach.

In achieving the overall goal of this dissertation, the following research questions will be answered.

1. Are integrated sanitation systems feasible for urban areas in Uganda?

2. Are integrated sanitation systems sustainable?

3. What are the main steps required in the planning of integrated sanitation systems?

1.7 Scope and Limitation of the Research

As highlighted in the justification of the study and its objectives, the integrated sanitation system approach proposed is considered to be applicable at community and city level. A certain level of existing sanitation structures and planning at the respective levels may be necessary requirements to enable the planning and possible implementation of integrated sanitation systems.

Owing to the fact that developing of a planning framework is an empirical process, modeling as well as observations of the interaction between sanitation related stakeholders is required. Moreover, consideration of technology and environment in addition to inputs from practical experience is necessary. Therefore, a study area which represents common sanitation challenges experienced in urban areas already mentioned in the research background was required. **UCU** in Mukono was selected as a case study area because the University has a considerable population and currently implements a number of measures to manage organic waste streams and opportunities exist for sanitation improvement. The University also heavily depends on firewood as a cooking energy source and is interested in using much cleaner sources such as biogas, which can be generated from organic waste management. In light of the situation at **UCU,** the need for sanitation improvement, available resources for biogas generation and clear indication of future interests stipulated in the University`s Strategic Plan are considered drivers for the integrated sanitation system approach.

By considering experiences from **UCU** as a case study, possible application of the integrated sanitation system approach in other schools, institution of higher learning, development estates, towns and city settings can be anticipated. Therefore, through focusing on the in-depth study of integrated sanitation systems for **UCU**, analytical generalisation of the feasibility and sustainability findings to include urban areas in Uganda with similar scope and challenges informs possible application of sanitation systems at a broader context. Moreover, by contributing to the development of a planning framework for the approach, the research intends to offer more insight on the approach while additionally exposing it for possible improvement.

Therefore, the present research is expected to contribute to the wealth of knowledge in the area of integrated sanitation by suggesting an approach for organic waste management in urban areas of Uganda. By developing a planning framework, the research goes as step further to give a road map to possible implementation of the approach, departing from a theoretical stance to a more practical application. Application of the integrated sanitation system approach planning framework would have to be adapted to local context taking into account aspects pertinent to the specific context.

1.8 Dissertation Outline

The research is organised in thirteen Chapters, each dealing with aspects related to the integrated sanitation system approach proposed and thus, contributing to the achievement of the research objectives. A brief overview of the dissertation structure is given below.

Chapter 1; gives an insight to the importance of sanitation and introduces the integrated sanitation system approach while briefly discussing its relevance. This Chapter further gives a justification for the research and highlights the research objectives. A brief discussion of the research scope and limitations is included before concluding the Chapter with the dissertation structure.

Chapter 2; presents the theoretical background of the research. It provides an analysis on state-of-the-art, advantages/benefits and drawbacks of existing sanitation approaches highlighting certain methods for technology assessment. Furthermore, sustainability analysis and its application are discussed with reference to the Helmholtz Concept of Sustainability. This chapter concludes with a comparative discussion of sustainability assessment of water and sanitation related projects based on sustainability indicators.

Chapter 3; presents a discussion of the sanitation status in Sub-Saharan Africa and reviews the key impacts of poor sanitation and the main hurdles to sanitation coverage in the region. Thereafter a discussion of the various sanitation systems used for key waste streams discharged in to the environment is carried out, highlighting the main motivation for an integrated sanitation system approach suggested in this research.

Chapter 4; describes the contextual framework of the research, highlighting the phases of the research.

Chapter 5; describes the research methodology and gives a detailed discussion of the tools and methods of analysis used to accomplish the tasks represented in the phases of the research.

Chapter 6; focuses on **UCU** as a case study and discusses the experimental analysis of substrates from **UCU** as part of the context assessment phase of the research.

Chapter 7; presents the design of sanitation system alternatives proposed for **UCU** and goes ahead to discuss the technical feasibility assessment of the sanitation system alternatives.

Chapter 8; deals with an assessment of the environmental feasibility of the integrated sanitation system alternatives proposed for **UCU** using life cycle assessment methodology.

Chapter 9; presents an assessment of the economic feasibility of the sanitation system alternatives proposed for **UCU** based on a cost benefit analysis approach.

Chapter 10; a socio-cultural assessment of the integrated sanitation system alternatives for proposed for **UCU** is carried out. Prior to the assessment, a stakeholder analysis is carried out. Using a stakeholder survey, the acceptability of the sanitation system alternatives is assessed. Moreover, a discussion of institutional and regulatory requirements for the sanitation systems proposed is also included in this Chapter.

Chapter 11; proceeds to present the sustainability assessment of the integrated sanitation system alternatives proposed for **UCU** with reference to multi-criteria decision analysis methodology. This chapter concludes with the ranking of sanitation system alternatives with reference to sustainability performance.

Chapter 12; presents a brief discussion of the implication of holistic feasibility and sustainability assessment results for the sanitation system alternatives proposed for **UCU**. The Chapter then concludes with the development of a planning framework for the integrated sanitation system approach.

Chapter 13: gives a summary of the research and goes further to give recommendations for further research.

2 Literature Review

Chapter 2 *presents a literature review relevant to the research, discussing the integrated sanitation concept and other related sanitation approaches applied in urban areas of developing nations. The review further highlights the gaps related to technology assessments cited in other sanitation approaches. The second part of this Chapter then discusses technology assessment with reference to sustainability and the applicability of the Helmholtz Concept for sustainability assessment. The Chapter concludes with a review on related technology assessment, using sustainability indicators.*

2.1 The Concept of Sanitation

Overtime, the definition of sanitation has become much broader and can no longer be limited to improved management of human excreta. Sanitation broadly consists of a process where people demand, effect, and sustain a hygienic and healthy environment for themselves and this is accomplished by erecting barriers to prevent the transmission of disease agents. Such a description considers sanitation as a concept rather than just a technology (UNICEF 1997). Ultimately, sanitation consists of both sanitation hardware[6] and software[7]. The sanitation system infrastructure is often referred to as the hardware. While the software encompasses activities that focus on sanitation promotion, which mainly include policies, legal and management frameworks, training, monitoring and evaluation investments among others (WaterAid 2011; Parkinson et al. 2014; Peal et al. 2010).

In the past, more focus was put on hardware components of sanitation while neglecting the software components and this was also evident from budget allocations which awarded large amounts of resources for sanitation infrastructural development (UNICEF 1997). However, over the last two decades, the trend has shifted with a conscious inclusion of software components during sanitation planning. The shift to factor in the software components in planning of sanitation was motivated by the realization that despite increasing sanitation coverage, proper usage of the facilities remained low and little or no benefit was derived (Parkinson et al. 2014; Andersson et al. 2016a). Research also shows that hygiene promotion can act as the means to create demand for sanitation and thereby increase coverage (Peal et al. 2010; Parkinson et al. 2014; UNICEF 2008).

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[6]Sanitation Hardware; Refers to sanitation facility infrastructure or toilets, pipes, sewers, ancillaries' equipment.

[7]Sanitation Software; Encompass activities that focus on the hygiene and/ or sanitation promotional activities. These may include policy development, training, monitoring and evaluation Peal et al. 2010

The term *"hygiene"* is used to refer to *behaviour/ measures, including but beyond the management of human faeces, which are used to break the chain of infection transmission in the home and community* (Peal et al. 2010). Thus, by considering sanitation and hygiene software, various interventions can be incorporated for improvement. Some of these interventions include; empowering individuals/communities, enabling behaviour change, creating demand for sanitation and hygiene related services, facilitation/ establishment of supply chains, and improvement of planning and implementation of projects (Peal et al. 2010). Generally, the realisation that these various aspects of sanitation can no longer be handled separately resulted in the promotion of the concept of integrated sanitation, which can be traced as far as two decades ago (EAWAG-SANDEC 2000; BMZ 2009; UNEP 2009)

2.1.1 Integrated Sanitation

Integration in sanitation, water and hygiene related sectors has been used to describe various traits. Extensive discussions related to integration of water, sanitation and hygiene have resulted in the development of approaches such as Integrated Water Resources management (IWRM), Integrated Urban Water Management (IUWM) and Integrated Solid Waste Management (ISWM) among others (Hassing et al. 2009; Jacobsen et al. 2012; UNEP 2016, 2009). With reference to sanitation, the integrated approach has been long proposed as a solution to challenges related to fragmentation of sanitation components and management (EAWAG-SANDEC 2008; WaterAid 2011). In so doing, integrated sanitation has been used to imply joint planning, implementation, and evaluation of activities across related sectors and programmes to achieve common goals. While another definition of integrated sanitation considers the incorporation of key aspects of sanitation such as technology, financing and hygiene promotion. Moreover, integrated sanitation has also been defined with reference to management of specific waste streams in sanitation systems, with the view of integration of technology to environmental, organisational and social conditions (WHO 2015; Hoffmann 2013; Jenssen et al. 2004).

With reference to the descriptions of integrated sanitation mentioned, practical examples of the integrated approach in sanitation include management of organic solid waste and wastewater. As such, large scale projects designed to manage organic waste streams and wastewater have been installed in wastewater treatment plants (WWTPs) of mostly developed countries. Such an approach has also been promoted in some cities with the objective of managing waste resources, while additionally recovering resources thus, some of these cities have been coined sustainable/smart cities (Lüthi et al. 2009; Andersson et al. 2016a).

In developing countries, examples of the integrated sanitation system approach have been mostly practiced in solid waste management, where a hierarchy of solid waste management is generally promoted. This hierarchy promotes the 3 R principle of reduce, reuse and recycle(UNEP 2009; World Bank 2012; David 2013). Other examples of integrated waste management include mainly the management of wastewater and to a small extent organic waste using **EcoSan** and bio-latrine systems (UNICEF 2014; Jenssen et al. 2004).

The ecological sanitation (EcoSan) principle basically consists of separating waste streams, saving water and energy, nutrient recycling, cost efficiency, and the integration of technology to environmental, organisational and social conditions. While the bio-latrines basically have a biogas digester connected to the latrine and the excreta is anaerobically digested in the digester, producing digestate and biogas. Despite these interventions, the application of the integrated sanitation approach in developing countries, especially in Uganda is still limited mainly to EcoSan and bio-latrines at residential and institutional establishments. Few examples of large scale application of integrated sanitation systems/ projects exist. Implementations of similar projects at Municipality or city/town level for instance, are still in the planning stages or final stages of construction. Case in point being, the National Water and Sewerage Corporation **WWTP** at Bugolobi**,** which is also expected to further manage sewage sludge generated from the plant with organic waste streams, generating biogas. This **WWTP** would be the first of its kind in the country and was expected to begin operation in the 1st quarter of 2017 (GEF 2015; Otage 2016). Overall, it can be seen that the definition of integrated sanitation is context specific and that examples of its application in Uganda are still limited to EcoSan and bio-latrines.

With reference to this research, the integrated sanitation systems approach considers interventions designed for improved management of organic solid waste, sewage and faecal sludge, animal dung and wastewater effluent reuse. As such, focus is drawn to management of specific waste streams in sanitation systems, with the view of integration of technology to environmental, economic and social conditions. Therefore, the holistic approach of sustainable sanitation, which recognises the technological aspects as well as the social, environmental and economic aspects related to managing the organic waste streams, is considered. In so doing, a shift from the "linear" concept, which considers the organic waste streams as "nuisance" to a closed loop concept, which recognises the organic waste streams as valuable "resources" is promoted (SuSanA 2008; Andersson et al. 2016a). Moreover, the integrated sanitation system approach suggested could be a viable option for organic waste management in peri-urban and urban areas in Uganda. As such, integrated sanitation systems could be applied in non-residential buildings or settlements, planned urban developments, peri urban areas as well as inter-city, middle or high income areas. Within these clusters located in urban and peri-urban areas, various neighborhoods, communities, cities or towns could be able to manage organic waste streams generated while recovering resources and this would make sanitation management attractive.

The integrated sanitation system approach suggested in this research is broached from the environmental sanitation concept. As already mentioned in Chapter 1, environmental sanitation considers a range of interventions designed to improve management of solid waste, sullage, surface drainage as well as vector control, especially in developing countries (WELL 1998; WSSCC, and WHO 2005; Parkinson et al. 2014). Particularly with respect to urban areas, inter linkage of solid waste, sullage, excreta, and storm water have justified the need for environmental sanitation services. In urban settings of developing countries for example, untreated wastewater and faecal matter has been known to end up in rivers, lakes or wetlands.

Moreover, the discharge of these waste streams to water bodies occurs either intentionally or indirectly through washing away by rainwater and flooding. Furthermore, wastewater and waste in different forms maybe indiscriminately disposed into public drainage systems, choking drainages especially during rainy season (BMZ 2009; Parkinson et al. 2014). Such practices result in the spread of diseases, posing more hygiene risks in addition to contamination of water bodies, leading to a multitude of health related and livelihood impacts. With reference to such a background and in an attempt to provide urban sanitation solutions, several environmental sanitation planning tools, giving guidance for various sanitation approaches have already been developed for households, communities, cities/towns.

2.2 Urban Sanitation Approaches and Planning Tools

In the past, conventional approaches to environmental sanitation were characterised by separate handling/management or in worst cases, negligence of certain components i.e. sullage, solid waste, drainage excreta etc. However, by the end of the 20th century it was realised that the conventional approach to environmental sanitation was unable to significantly improve the service backlog, especially in most of the developing world (EAWAG-SANDEC 2005; Lüthi et al. 2009). This prompted the proposal of guiding principles as the basis for future planning and implementation of environmental sanitation services. These principles referred to as "*Bellagio Principles*" were passed in the 5th Global Forum in November 2000 (EAWAG-SANDEC 2000). With reference to environmental sanitation, the *Bellagio principles* of sustainable development are summarised into four key points that state;

1. Human dignity, quality of life and environmental security at household level should be at the centre of the sanitation approach which should be responsive and accountable to needs and demands in the local and national setting.
2. In line with good governance principles, decision making should involve participation of all stakeholders, especially the consumers and providers of services.
3. Waste should be considered a resource, and its management should be holistic and form part of integrated water resources, nutrient flow and waste management processes.
4. The domain in which environmental sanitation problems are resolved should be kept to the minimum practicable size (household, neighborhood, community, town, district, catchments, and city) and wastes diluted as little as possible.

Thus, with reference to the *Bellagio principles* stated, sanitation approaches for households, communities and cities/towns were conceived and respective planning tools developed. Noteworthy is that experience from international development work related to water and sanitation over the past five decades has drawn focus on more participatory bottom-up methodologies and planning tools rather than the traditional top-down strategy. These participatory planning strategies, which are adopted in the sanitation approaches later discussed are mostly hinged on five key principles which include; (1) participation, (2) capacity building, (3) economic efficiency, (4) technical flexibility and (5) feedback.

2.2.1 Participation

The requirement for stakeholder participation is no longer considered optional but a crucial component of sanitation planning, especially when longevity of the system or programme is envisioned. Seen as a way of developing ownership, community empowerment, and promotion of demand-driven economic models for sanitation, stakeholder or community participation is being incorporated at all stages of planning. The participatory approach is often hinged to decentralised democratic processes which ideally seek to manage problems close to their source. The component of participation in planning therefore requires identification of various stakeholder groups, their unique set of priorities and drivers for sanitation improvements (Kvanström et al. 2008; Andersson et al. 2016a; ADA 2008; Andersson et al. 2016a).

2.2.2 Capacity Development

Sanitation service delivery is often marred with problems related to insufficient staff and inadequate technical capacity. Moreover, lack of institutional capacity defined by managerial and technical competences to develop and implement strategic plans is also deficient in most cases (Parkinson et al. 2014; Lüthi et al. 2011b). Therefore, capacity building can address these problems, especially through educational measures for awareness raising, social marketing and capacity development. Health education, social marketing and sanitation promotion efforts have been known to increase awareness, highlighting the need for improved sanitation and boosting demand for services. Furthermore, there is additional need for development of technical and organisational capacity of communities or stakeholder groups. This enables participation in planning, management and maintenance of sanitation systems once installations are accomplished. As such, capacity development may include training of the different stakeholder groups in both the formal and informal sector, who will in turn stimulate the market (Lüthi et al. 2011a; Kvanström et al. 2008; Peal et al. 2010)

2.2.3 Economic Efficiency

Similar to any investment, marketing of sanitation services needs to respond to realistic assessments of demand. Thus, a clear understanding of the demand for sanitation services should go beyond demand identification to ensure that realistic economic efficiency can be reflected. This requires a more holistic approach, which responds to realistic assessments of demand while ensuring the services are affordable for all levels for the users. A general projection of demand from demographic and income analysis is no longer considered a representative approach of assessing economic efficiency. By adapting the more realistic approach, demand-based economic models linked with both participatory approaches and capacity building are attained since the models rely on consumer input and social marketing strategies (Kvanström et al. 2008; Luethi 2012).

2.2.4 Technical Flexibility

Based on the needs of the consumers and related costs, various sanitation options can be designed. Usually after taking into consideration a wider view of sanitation itself and factoring in linkages with water supply and solid waste systems, a wider range of technical options maybe designed. Various design considerations can factor in separate or integrated management of waste streams. Moreover, appropriate level of service provision i.e. household, centralised etc. should be considered when planning the sanitation system configuration. In considering all these aspects, focus is also drawn to the functionality of the sanitation system rather than the technology that would be applied (Kvanström et al. 2008; Vleuten-Balkema 2003).

2.2.5 Feedback

Without taking into consideration feedback from various entities or stakeholders, monitoring and evaluation of sanitation becomes a major challenge. The feedback principle basically consists of soliciting and responding to feedback. Response to both consumers and technical feedback are often incorporated in other principles as well. Nevertheless, incorporation of response and feedback within its own principle limits the risk of being overlooked in more core actions of the other processes. By incorporating feedback, the entire planning process is linked in an iterative and participatory way and this allows for technical, environmental, and socio-economic issues to be assessed together throughout the process. Ideally creating manageable steps towards achieving sanitation objectives should be reflected in the planning and implementation stages while portraying an incremental approach. Such a trend would increase incentives to reach immediate goals while keeping the project on track through consistent evaluation of progress (Kvanström et al. 2008; Parkinson et al. 2014).

Therefore, given that the integrated sanitation system approach in this research is based on the environmental sanitation concept, some of the approaches and tools relevant for urban areas are discussed.

2.2.6 Household Centered Environmental Sanitation (HCES)

HCES was developed by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) for urban settings based on the "*Bellagio principles*". The **HCES** sanitation approach was designed to respond to household needs and priorities regarding urban environmental sanitation services while involving stakeholders at every level. Specifically, households and neighborhoods are at the core of the planning, implementation and operation processes of this approach. The **HCES** approach promotes a shift from the past central planning approaches as it places the household and neighbourhood at the core of the planning process instead of central authorities or governments (EAWAG-SANDEC 2005). The **HCES** approach responds directly to needs and demands of the users while trying to avoid problems resulting from purely "bottom-up" or "top-down" approaches.

This is achieved by employing elements in an integrated framework which is also characterised by incorporating multi-sectoral and multi actor aspects. Multi sector involvement takes into consideration water supply, sanitation, storm drainage and solid waste management. While the multi-actor aspect emphasises the participation of all stakeholders starting from the household and progressing to the neighbourhood. Stakeholder participation is incorporated at planning and implementation phases of urban environmental sanitation services. Moreover, the **HCES** approach is also based on;

- Household 'effective' demand which leads to sustainable and balanced services.
- The concept of 'zones' and solving problems within the 'zone' nearest to where the problems arise
- The use of a 'circular model' which emphasises resource conservation and reuse to reduce waste disposal rather than the traditional linear model of unrestricted supply and subsequent disposal. As such, **HCES** offers the promise of overcoming the shortcomings of unsustainable planning and resource management practices of conventional approaches (EAWAG-SANDEC 2005).

The focus on households in the **HCES** approach is hinged on the understanding that households are the basic level at which decisions on investments are made and where behavioral changes are initiated. **HCES** additionally considers spatial, institutional and decision-making "domains" necessary for planning (EAWAG-SANDEC 2005). The strengths of **HCES** approach is that it offers the possibility of providing economic and non-economic benefits, an integrated affordable and sustainable package of services, meeting the users' priorities. Despite the strengths of **HCES** approach mentioned, by the size of its scope **HCES** requires collaboration and coordination between multiple agencies/actors that may have different capabilities and varying level of commitment to working together. As such, **HCES** should only be considered where there is a strong political commitment to sustain the process since this would be essential to its success. The **HCES** approach recognises five organisational and geographical zones which include the household, peri-domestic or community, ward, city, and city fringe as shown in Figure 2-1.

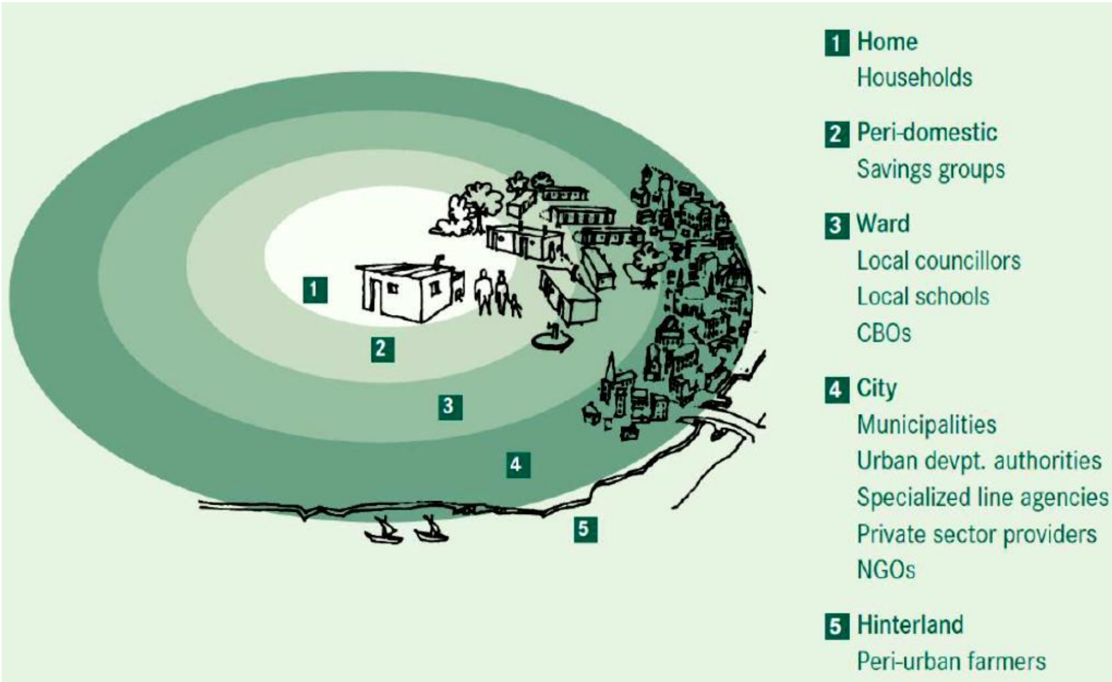


Figure 2-1; HCES Five Organisational and Geographical Zones
Source: (Luethi 2012)

The organisational zones also referred to as domains include; *households, neighborhoods or community, city and external city* areas as shown in Figure 2-1.
The *household domain* basically includes the private sphere where households are responsible for their decisions regarding behaviour and investments to improve sanitation facilities.
The *community domain* is characterised by communities collectively involved in planning activities. Often the case, local level political administrators and providers of services within communities are also involved in decision making.
While in the *city domain* services may be centrally planned, organised and financial decisions could be taken by central or city authorities. Key actors in the *city domain* include local authorities, government bodies and utilities responsible for planning sanitation etc. (Parkinson et al. 2014; EAWAG-SANDEC 2005; Luethi 2012).

To enable the implementation of the **HCES** approach, a guideline/planning tool was developed and it communicates key aspects of the enabling environment for **HCES** application in addition to describing steps involved in developing and implementing the approach. Development and implementation of **HCES** involves a ten step process which includes; 1) request for assistance, 2) launch of the planning and consultative process, 3) assessment of current status, 4) assessment of user priorities, 5) identification of options, 6) evaluation of feasible service combinations, 7) consolidated sanitation service plans for the study area, 8) finalising consolidated sanitation service plans, 9) monitoring, internal evaluation and feedback and 10) implementation.

With reference to technology assessment, a general recommendation is that the project implementers should review the potential and limitations of existing technical alternatives, emphasising on decentralized systems at household and community levels. The **HCES** guideline generally mentions that examination of technical, institutional, financial and social feasibility of each alternative and assessment of other factors such as impact on the environment should be considered. **HCES** proposed assessment criteria includes;

- user friendliness
- environmental friendliness
- saving of natural resources
- removal efficiencies for different kinds of pollutants
- financial requirements
- institutional requirements
- requirements for skilled labour

2.2.7 Community Led Urban Environmental Sanitation (CLUES)

The **CLUES** approach was also developed by **EAWAG** with reference to the *Bellagio Principles* mentioned and is based on the experiences from piloting **HCES** in Africa, Asia and Latin America. The **CLUES** approach focuses on community level involvement in urban sanitation planning and decision-making processes. Similar to **HCES**, the **CLUES** approach also considers multi-sector and multi-actor aspects accounting for water supply, sanitation, solid waste management and storm drainage management. In addition, emphasis on stakeholder participation at an early stage in the planning process is incorporated(Lüthi et al. 2011a). The approach is meant to complement city-wide infrastructure planning approaches such as the **Sanitation 21** planning framework discussed later. Taking into consideration that the **CLUES** also considers multi sector and actor involvement, requirement for collaboration and coordination between multiple agencies/actors often having different capabilities could become a potential weakness of the approach.

Similar to **HCES**, the guideline for planning and implementation of **CLUES** among others communicates the cross cutting tasks of awareness raising, capacity development, process monitoring and evaluation reflected in seven steps. These steps include; 1) process ignition and demand creation, 2) launch of the planning process, 3) detailed assessment of the current situation, 4) prioritisation of the community problems and validation, 5) identification of service options, 6) development of an action plan and 7) implementation of the action plan. A system approach is adopted when considering the technological alternatives suggested under the **CLUES** approach. Therefore, all components required for the adequate management of the different waste streams, the users of the system, collection at household level in addition to transportation, treatment and management of end products are considered. With the guidance from experts, feasible alternatives are selected based on the local context. Thus, the existing infrastructure, physical characteristics of the site, re-use opportunities, economic limitations of the community and responsible agencies are considered (Luethi 2012).

No particular criteria for selection of technologies are given in **CLUES** guidelines although emphasis is placed on the importance of reaching an agreement between community and local authority regarding the financial and management implications of the selected system(s).

2.2.8 Sanitation 21

Sanitation 21 was developed by the International Water Association (IWA) in 2006. The approach is a simplified representation of the complex urban sanitation planning process. **Sanitation 21** was developed to address some key failings in current sanitation approaches which result in a mismatch between the stated objectives of investments and the outcomes. As such, the supply of appropriate services does not meet the demands and capacities of the actors in a particular domain. The causes of the mismatch mentioned is related to inability of approaches to meet the rapidly changing urban context and diverse conditions in addition to failure to make realistic assessment of short term inertia, which in turn impedes capital investment.

The **Sanitation 21** approach specifically focuses on excreta management and explores how better planning for excreta management can be achieved so that investments are more likely to generate the needed health and environmental benefits (IWA 2006; Parkinson et al. 2014). After recognising the complexity surrounding the development of tailor- made sanitation solutions, the approach attempts to answer questions like *" will it work? "* and *"does it fit the purposes.* **Sanitation 21** goes a step further to focus on dense settlements with multi-layered sanitation needs and some of these settlements include urban utility settings, towns and small urban settlements instead of rural communities. Thus, the approach also includes a guide for planners/designers and helps to build bridges between institutional analysis and technical planning (Peal et al. 2010; IWA 2006)**.**

Sanitation 21 promotes an analysis of the objectives of a sanitation system, considering an integral part of achieving improvements in urban sanitation across all domains. The domains include; beyond the city, city, neighborhood and household. In case of system implementation, the "cross-domain analysis" additionally covers the impact behavior of each domain in addition to the technical option which matches the system in the specific domains and required management of domains (IWA 2006). Initially developed with three main steps, **Sanitation 21** was eventually updated and consists of five process stages. These stages include; 1) build institutional commitment and partnership for planning, 2) understand the existing context and define priorities, 3) develop systems for sanitation improvement, 4) develop models for service delivery and 5) prepare for implementation. With reference to assessment, emphasis is placed on assessment of the costs for the proposed alternatives. The most cost-effective sanitation solutions are obtained on the basis of life-cycle analysis, taking into consideration all costs incurred and revenues generated over the total lifespan of the investment (Parkinson et al. 2014; IWA 2006).

2.2.9 Participatory Hygiene and Sanitation Transformation (PHAST)

Although developed prior to the passing of the "*Bellagio Principles*" for sustainable sanitation, the **PHAST** approach is discussed in this section because it additionally focuses on hygiene (Sawyer et al. 1998). This sanitation approach seeks to help communities improve hygiene behaviour and encourage better community management of water and sanitation facilities. Based on an innovative set of participatory techniques, the main goal of the **PHAST** approach is to improve the health and living conditions of people, especially the poor who may face the highest risks. To achieve this goal, the **PHAST** approach has the objectives of improving sanitation and hygiene behaviour while preventing diarrhoeal diseases and encouraging community management of water use and sanitation (UNICEF 2008; Sawyer et al. 1998). Thus, the achievement of **PHAST** objectives is accomplished by engaging in the following activities;

- Emphasising the relationship between sanitation, hygiene and health;
- Increasing the self-esteem of community members
- Empowering communities to assess hygiene and sanitation conditions and practices and plan and monitor improvements; and
- Encouraging communities to own, operate and manage water and sanitation services

Applied in both rural and urban settings in Africa and other Asian countries, the idea behind **PHAST** is to create understanding and attempt to link this understanding to real action. As such, **PHAST** works on the premise that while communities gain awareness of their water, sanitation and hygiene situation through participatory activities, they are empowered to develop and carry out their own plans to improve the identified situation. The plans adopted by the communities could range from construction and management of new physical facilities to individual and collective behaviour change (Peal et al. 2010).

Experiences from application of **PHAST** in African countries indicate that the sanitation approach/tool has contributed to the change of communities' perceptions and behaviour regarding sanitation and hygiene. Moreover, **PHAST** can be used as a means of monitoring and evaluating community perceptions and behaviour over time even though trained staff would be required to enable the process. The key weaknesses associated with the application of **PHAST** include; weak inter-sectoral collaboration due to varying actor interests/capacity, weak follow-up mechanisms and high logistical requirements since trained personnel are required to enable approach implementation.

Moreover, implementation of the approach can be time intensive since the beneficiary communities should be available to go through the participatory exercises (UNICEF 2008).
PHAST uses a seven step participatory approach to facilitate community planning and the include; 1) problem identification, 2) problem analysis, 3) planning for solutions, 4) selecting options, 5) planning for new facilities and behaviour change, 6) planning for monitoring and evaluation, 7) participatory evaluation. A clear emphasis on feedback from participants informs the entire process, including selection of sanitation options (Sawyer et al. 1998).

Although the **PHAST** framework was developed much earlier i.e. 1998, it is evident that the *Bellagio principles* are enshrined within the approach. *Human dignity* is promoted in ensuring hygiene and the *good governance* aspects are reflected in the participatory approach of **PHAST**. While, consideration of *waste as resource* can be achieved from improved management of water and sanitation facilities. The fact that the approach focuses on communities, ensures that sanitation management is kept to the minimum *practicable size*.

In implementing the various approaches discussed, often the case sanitation systems are used. Sanitation systems take into consideration all components required to accomplish an intervention or the management of waste streams, which in most cases may consist of human excreta. The sanitation systems or options generally take into consideration a combination of technologies/processes through which the products or waste streams flow. Prior to implementation of the various interventions or sanitation system options, evaluation of the sanitation systems may be accomplished using feasibility and, or sustainability assessments. As such, having the necessary guidance on how to accomplish such assessments is crucial. Table 2-1 gives an overview of the sanitation approaches discussed with reference to their aims, focus and assessment of sanitation technologies.

Table 2-1: Summary of Sanitation Approaches Discussed

Analysis	**HCES**	**CLUES**	**Sanitation 21**	**PHAST**
Aim	To create a planning approach based on the *Bellagio Principles* of sustainable sanitation.	To enable planning and implementation of cost effective environmental sanitation services.	To address key failings in current planning approaches which result in a mismatch between the stated investment objectives and outcomes	To help improve hygiene behaviour, prevent diarrhoeal diseases encourage community management of water and sanitation facilities
Focus	The approach focuses attention on issues of human dignity, local participation, holistic waste management and solving sanitation problems close to the source i.e. households, neighbourhood.	Focuses on multi-actor and multi-sectoral approach in ensuring urban environmental sanitation services	The main focus is drawn on excreta management, exploring better planning measures, so that investments are more likely to generate the needed health and environmental benefit	Focuses on behaviour change at community level for improved management of own water and sanitation facilities
Technology assessments considerations	The approach proposes a link between the existing service in higher levels such as municipalities and the proposed service at a household level. Once the various technical combinations have been matched with various institutional options, a list of criteria is used for technology selection.	Expert input guided by informed-choice catalogues guide technology selection. However, in collaboration with stakeholders, the financial, management become the important consideration in selecting a technology.	Emphasis is placed on assessment of the costs for the proposed alternatives. The most cost-effective sanitation solutions are obtained on the basis of life-cycle analysis.	Assessment of sanitation options/alternatives based entirely on participant feedback

Source: Author

From the review of sanitation approaches discussed, it is clear in the steps involved for each of the plans that stakeholder involvement is a crucial component that can be traced at different levels of all the approaches, promoting a participatory approach. From the summary presented in Table 2-1, it is also evident that the approaches focus on a range of aspects i.e. hygiene, sanitation and specifically excreta management. Moreover, emphasis is placed on offering sanitation services at specific domains i.e. household, community, or city etc. Although reference to various organisational zones is mentioned in the **HCES** approach, focus is still drawn to the main involvement of the household domain in the planning and implementation processes. Given that urban and peri-urban areas could consist of variable domains i.e. neighborhoods, communities, towns, cities etc., which often have different sanitation needs, provision of sanitation services may invariably require a mixture of sanitation systems that are appropriate for the different domains. As such, having a sanitation approach, which holistically considers environmental sanitation services for urban areas while incorporating the different domains i.e. community and city/town in a single guideline/tool could be attractive.

a) *This dissertation suggests an integrated sanitation system approach, which specifically considers combined management of organic waste streams generated from urban areas i.e. neighbourhood/ community and city/town domains. As such, the approach considers management of various organic waste streams i.e. more than just human excreta in more than just one domain.*

The four sanitation approaches reviewed provide different frameworks for selection of a technology. The **HCES** approach suggests a list of criteria for technology selection. **Sanitation 21** and **CLUES** promote generic analysis on several sanitation systems to assist the decision makers, while **PHAST** depends on participant feedback for assessment of sanitation options. Despite suggesting that technical, institutional, financial and social-cultural assessments should be carried out for the sanitation system options, a systematic way to accomplish the evaluations is not really included in the frameworks. Furthermore, there is no reference to the meaning of sustainable technology options with regards to a particular context. Moreover, a procedure for an inclusive assessment of the sustainability of different sanitation technology options is absent in the frameworks/guidelines for these sanitation approaches. Given that most of these environmental sanitation approaches were based on the *Bellagio principles* of sustainable sanitation, the absence of reference to sustainable sanitation technology and a procedure for sustainability assessment of the sanitation technology options reveals certain gaps in these approaches.

b) *Therefore, by carrying out a holistic feasibility assessment of the integrated sanitation system alternatives, it is expected that the findings from the assessment will additionally inform the sustainability assessment of the sanitation systems. As such, it is expected that this research will additionally give guidance on how to incorporate sustainability assessments for integrated sanitation systems by suggesting a planning framework.*

2.3 Sustainable Development.

Sustainability or sustainable development is commonly referred to by the Brundtland commission report definition as, "*development that meets the needs of the present without compromising the ability of future generations to meet their own* needs" (WCED 1987). Despite portraying an all-inclusive and broad scope, sustainable development concept has been criticised as being ambiguous since the initial definitions are considered "vague". As such variable definitions of sustainability have cropped up over time. For instance, sustainability has been defined as the study of how natural systems function, remain diverse and produce everything needed for the ecology to remain in balance. (Gibson and Hassan 2005) further suggest that sustainability stands as a critique, which challenges prevailing assumptions, institutions and practices. In spite of the ambiguity surrounding sustainability as a concept, perhaps the most important insight was that achieving human well-being in the long-term depends on convoluted combination of social, economic and ecological factors or pillars. These three key factors are intertwined in different ways depending on local and regional conditions (Gibson and Hassan 2005; Jörrisen et al. 1999).

Overtime, debates on the topic have suggested that sustainability depends on five pillars not just three and these pillar consist of ecological, economic, social, political/institutional and cultural pillars (Hawkes 2001; Gibson and Hassan 2005; SuSanA 2008). Moreover, attempts have been made to fine tune concept of sustainability so as to obtain much more clear definitions or meaning. Some of such attempts have resulted in development of action plans such as Agenda 21 and most recently the sustainable development goals(**SDG**) (UN 1992, 2015).

2.4 Shaping Technology with Reference to Sustainability Principles

Sustainability has been considered an integrative concept, which considers environmental, social and economic aspects as three fundamental dimensions. These three dimensions have often been denoted as pillars of sustainability, which reflect that responsible development requires consideration of natural, human, and economic capital or in other words the planet, people, and profits (Hansmann et al. 2012; WCED 1987). Nevertheless, a paradox exists with regards to technology development. On the one hand, specifically science based technology has offered the promise of a better world through the elimination of disease and material improvements to standards of living. On the other hand, technology development is responsible for resource extraction, emissions of dangerous materials and pollution of the environment which end up creating unprecedented environmental catastrophes and irreversible damage to the biosphere (Vergragt 2006; Grunwald 2012). Therefore, taking into consideration the ambiguity associated with technology development, there is need to shape technology with respect to sustainability principles. This would prove that the technology is compatible with the society for which it would be applied thus, avoiding any negative effects on the society (Ludwig 1997; Grunwald 2012). In ensuring compatibility with society, technical efficacy becomes one of the targets and it is with reference to such requirements that technology assessment emerged.

2.4.1 Sustainability based Technology Assessment

Developed in the 1960`s, technology assessment was initially based on narrow considerations of technical efficacy and immediate direct and observable results. Over time however, increasing knowledge of the indirect impacts of technology upon environment and society led to systematic study of the related effects. The systematic studies attempt to examine the possible effects on society and on its ecological environment while reflecting on when a technology is introduced, extended, or modified. As such, the goal of technology assessment is to examine a specific technology as components, subsystems, or systems of a concrete social system. Moreover, the evaluation of implications of the technology include, but extend beyond its technological accomplishments (Arbulu and Félix 1986; Ported 1995; Braun 1998). Based on such an evolvement, it is no wonder that technology assessment has been variably defined by researchers.

Technology assessment is an attempt to establish an early warning system to control, direct, and if necessary, restrain technological development so as to maximize the public good while minimizing the public risk (Arbulu and Félix 1986)

Technology assessment is a systematic attempt to foresee the consequences of introducing a particular technology in all spheres it is likely to interact with (Braun 1998).

Technology assessment is a strategy that has to provide information and knowledge on technical systems. Ultimately the knowledge encompasses development and application of technical systems and the connections between economic, social and political systems and the respective impacts on the environment (Ludwig 1997).

Technology assessment is considered a strategy that is used to provide information and knowledge on technical systems. The knowledge provided includes development and application of technical systems and the connections between economic, social and political systems, and impacts on the environment. Thus, in the ideal case technology assessments aim to satisfy the highest requirements of timeliness, comprehensiveness, participation and transparency. It is also because of this board goal that these assessments are criticised. Nevertheless, the goals can be used as necessary guides in the desired direction even though the actual achievement might fall short of the goal (Ludwig 1997; Braun 1998).

Braun (1998) suggests that technology assessment is perhaps more of an attitude than a method. It is basically the attitude of attempting to take a holistic view of a technology within its broad social setting, thereby avoiding a narrow view. This implies that a variety of methods can be used for technology assessments and these methods are largely borrowed from the various fields. Taking into account the complexities in the interaction of technology and sustainable development already mentioned, there is a strong need to integrate a sustainability concept into technology assessments and various methods have been used in an attempt to accomplish this task. Some of the methods used attempt to evaluate the sustainability of a technology in a single perspective using *Material Flow Analysis* (MFA), *economic analysis* and *life cycle assessment*.

However, in cases where complex and non-linear systems exist, which are often characterised by many unmeasurable qualities and partial uncertainty of interactions, then the single perspective assessments may not suffice. In such cases, other methods that include several dimensions of sustainability, such as *multi- criteria analysis* and *system analysis* can also be used. Noteworthy is that system analysis is mostly a 'tailor-made' method such that comparison of the different system analyses is difficult given that the goals, scopes and assumptions considered differ per analysis or study considered (Vleuten-Balkema 2003; Nayono 2014)

c) *Recognising that the sanitation system technologies may often involve multiple dimensions, this research adopts a multi-dimensional approach in technology sustainability assessment.*

2.5 Guidance to Sustainability Assessment: Reference to Helmholtz Concept of Sustainability

Sustainability is considered an integrative concept, which considers environmental, social, and economic aspects as three fundamental pillars. Despite this assertion, the interactions between the various pillars of sustainability in addition to connectivity of their relationships pertinent to sustainability are complex. Moreover, the frequent occurrence of competing effects makes sustainability assessment additionally complicated (Grunwald 2004). With reference to such anticipated complexity, (Grunwald 2004) further asserts that strategic knowledge is necessary to support opinion formation and decision-making processes in relation to sustainability. Strategic knowledge for sustainable development generally consists of the necessity to combine *orientation knowledge, system knowledge and knowledge for action*.

Orientation knowledge includes the appraisal of societal circumstances and developments in addition to consideration of global trends and measures. As such, the orientational criteria, which permit comprehensible and transparent differentiation in `sustainable' and `non-' or `less sustainable` aspects are required. *System knowledge* attempts to obtain sufficient insight into natural and societal systems in addition to the knowledge of the interactions between society and the natural environment. *Knowledge for action* is basically foresighted knowledge of the sustainably efficient measures and their effects since this is a decisive prerequisite for informed decision-making. Particularly with reference to the *orientation knowledge* requirement, certain essential criteria have to be fulfilled for practical relevance to be achieved (Grunwald 2012; Grunwald 2004). These criteria are include;

- *a clear object relation*: by definition it must be clear what the term applies to and what not, and which are the subjects to which assessments should be ascribed;
- *the power of differentiation:* clear and comprehensible differentiations between 'sustainable' and 'non- or less sustainable' must be possible and concrete ascriptions of these judgments to societal circumstances or developments have to be made possible beyond arbitrariness;

- *the possibility to operationalise:* the definition has to be substantial enough to define sustainability indicators, to determine target values for them and to allow for empirical 'measurements' of sustainability.

The integrative concept of sustainable development which was developed by (Kopfmüller et al. 2001) claims to meet the criteria for practical relevance mentioned. Developed at the Institute for Technology Assessment and System Analysis at the Karlsruhe Research Centre, which is part of the Helmholtz Association, the integrative concept provides a theoretically founded approach. The approach aims to operationalise the guidance and is an operable analytical tool for sustainability analyses, applied in various research projects (Kopfmüller et al. 2001; Braeutigam and Gonzalez 2006; Nayono 2014). The starting point of the integrative concept is on three constitutive elements which include;

- Inter- and intra-generational justice, equal in weight;
- The global perspective regarding goals and action strategies; and
- An enlightened anthropocentric approach in the sense of the obligation of mankind to interact cautiously with nature out of a well-understood self-interest, referring for instance to long-term preservation of nature.

Grunwald (2012) points out that the three constitutive elements are further operationalized in two steps. The first step includes translation of the elements in to three general goals of sustainable development which include; *securing human existence, maintaining society's productive potential and preserving society's options for development and action*. The second step then concretises the goals by sustainability principles which apply to various societal areas or to certain aspects in the relationship between society and nature.

The integrative concept of sustainable development distinguishes between *substantial principles* and *instrumental principles*. The *substantial principles* identify minimum conditions for sustainable development that should be assured for all people living in present and future generations. While the *instrumental principles* describe necessary framework conditions for the realisation of the substantial minimum conditions. The principles mentioned have to be further concretized by suitable indicators which unfold the normative aspects of sustainability as goal orientation for future development and as guidelines for action. Moreover, the *instrumental* and *substantial principles* provide criteria to assess the sustainability performance of particular societal sectors, spatial entities, technologies, policies (Grunwald 2012). Braeutigam and Gonzalez (2006) give a summary of the architecture of the Helmholtz integrative concept for sustainable development shown in Figure 2-2.

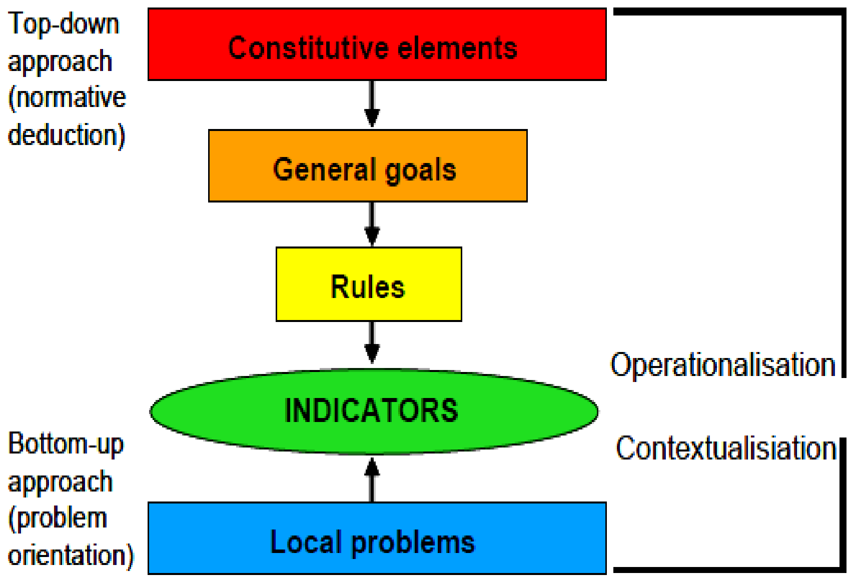


Figure 2-2: Architecture of the Helmholtz integrative concept for sustainability
Source: (Braeutigam, and Gonzalez 2006)

Despite the Helmholtz integrative concept meeting the criteria as guidance for sustainable development, its applicability for technology assessment guidance still falls short. Grunwald (2012) further states *that "the integrative sustainability concept has not been specifically developed as an instrument for technology assessment, but refers to the development of society as a whole from a global perspective" (Grunwald 2012).* With reference to this assertion, technology is just seen as one component of societal relations and development

In the event that the integrative sustainability concept is used as a normative framework for technology assessment, then an understanding that technology can only make positive or negative *contributions* to a sustainable development has to be maintained. Moreover, consideration of these contributions always has to be factored in against the background of other societal developments. To enable technology assessment, determination of which principles of sustainability are relevant is a crucial step. This is mainly because sustainability principles cannot be directly transferred into guidelines for technology design or even performance characteristics for technology. Principles do not refer to technological requirements but to aspects of society's economic behaviour, where the technology is just one aspect among many others. As such, if the consequences of the technology are the main focus, then context has to be taken into consideration (Grunwald and Rösch 2011; Grunwald 2012).

Reflection of the context can be accomplished by asking questions such as;

- Which problems are relevant for sustainability in the respective field,
- Which technological and societal conditions apply,
- How are the technological and societal conditions connected,
- How does the whole structure, which is often complex relate to the approach of the whole system of sustainability principles.

By reflecting on the questions noted, it is clear that sustainability principles do not have a prescriptive character for technology design (Grunwald 2012). The sustainability goals and principles of the Helmholtz integrative concept are described by Grunwald (2012) in the following Section.

2.5.1 Securing Human Existence

With regards to this goal, the central necessity which can be derived from the postulate of justice is that *the present generation* should not destroy the basis of its own subsistence and that of *future generations*. Fundamental preconditions for this goal are summarised in Table 2-2

Table 2-2: Substantial sustainability principles related with the objective "Securing human existence"

	Short titles	**Principles**
1.1	Protection of human health	Hazards and unacceptable risks to human health due to anthropogenic environmental burdening must be avoided
1.2	Ensuring satisfaction of basic needs	Every member of society must be assured a minimum of basic supplies (housing, food, clothing, health care) and protection against fundamental risks to life (sickness, disability).
1.3	Autonomous subsistence based on own income	All members of society must be given the possibility of securing their existence by voluntarily undertaken activities (including education of children and care of the elderly).
1.4	Just distribution of chances for using natural resources	Utilisation of natural and environmental resources must be distributed according to the principles of justice and a fair participation of all persons affected.
1.5	Reduction of extreme income and wealth inequalities	Extreme inequalities in the distribution of income and wealth must be reduced.

Source: (Grunwald 2012)

2.5.2 Maintaining Society's Productive Potential

Under this goal, the future generations should find comparable possibilities of satisfying their needs and these may not necessarily be identical to those of the present generation.

It can therefore be derived from this postulate that with regards to *materials requirement*, the productive capacity of global society has to be upheld through time in a quite general sense as a generic goal of sustainable development. In general, sustainable development demands that the stock of capital which exists within a generation be handed down as undiminished as possible to future generations (Grunwald 2012). Table 2-3 summarises the minimum prerequisites for achieving this goal.

Table 2-3: Substantial sustainability principles related with the objective "Maintaining society's productive potential"

	Short titles	**Principles**
2.1	Sustainable use of renewable resources	The rate of utilising renewable resources is not to exceed the regeneration rate or endanger the ecosystems' capability to perform and function.
2.2	Sustainable use of non-renewable resources	The range of proven non-renewable resources must be Maintained.
2.3	Sustainable use of the environment as a sink	The release of substances is not to exceed the absorption capacity of the environmental media and ecosystems.
2.4	Avoiding technical risks with potentially catastrophic impacts	Technical risks with potentially catastrophic impacts on humanity and the environment must be avoided.
2.5	Sustainable development of man-made, human and knowledge capital	Man-made, human, and knowledge capital must be developed in order to maintain or improve the economy's performance.

Source: (Grunwald 2012)

2.5.3 Keeping Options for Development and Action Open

In this third goal, the principle of not endangering the satisfaction of future generations' needs cannot be limited to *material* necessities but has to include *immaterial* needs as well. Evidently for human existence, immaterial aspects such as integration in social and cultural relationships, communication, education, contemplation, aesthetic experiences, leisure, and recreation are equally as indispensable as the *material* bases of subsistence. Hence, it is only when these needs have also been satisfied that it can be considered that a stable and acceptable level of human existence has been reached (Grunwald 2012). The minimum prerequisites for achieving this goal are summarised in Table 2-4.

Table 2-4: Substantial Sustainability Principles related with the objective "Preserving Development and Action Options"

	Short titles	Principles
3.1	Equal access for all people to information, education, occupation	All members of society must have equal chances to access education, occupation, information, and public functions as well as social, political, and economic positions.
3.2	Participation in social decision-making processes	Every member of society should be given the opportunity to participate in relevant decision-making processes.
3.3	Conservation of the cultural heritage and diversity	Human cultural heritage and cultural diversity must be preserved.
3.4	Conservation of the cultural function of nature	Cultivated and natural landscapes or areas of special uniqueness and beauty have to be preserved
3.5	Conservation of social resources (tolerance, solidarity, etc.)	To ensure societal cohesion, the sense of legal rights and justice, tolerance, solidarity, and perception of common welfare as well as the possibility of non-violent conflict settlement must be enhanced

Source: (Grunwald 2012)

Generally, the Helmholtz integrative concept attempts to understand sustainability per definition without quickly reducing it to merely ecological aspects. This has proven the richness of the spectrum of aspects of sustainability. The concept recognises that criteria of resource economics and ecology are of special importance. It also brings to the forefront crucial aspects of participation and equal opportunities in addition to giving guidance on how to deal with technical risks and aesthetic values of landscapes. Moreover, the shaping of reflexive societal decision processes and the modeling of economic framework conditions as well as aspects of human health are incorporated (Grunwald 2012; Grunwald and Rösch 2011).

d) *In this dissertation, reference is made to the Helmholtz concept of sustainability in addition to findings from the feasibility assessments to enable sustainability assessment of integrated sanitation system alternatives.*

2.6 Application of Indicators for Sustainability Assessment

As earlier mentioned, sustainability is a multi-dimensional concept, which fundamentally integrates economic, social and environmental aspects although, overtime other aspects such as culture and technological aspects are also incorporated (Hawkes 2001; Gibson and Hassan 2005). Based on such a scope, a comprehensive method is required for the assessment of sustainability if all aspects are to be captured. Among several sustainability assessment methods, indicator sets are an appropriate instrument for a multi-dimensional representation.

Waas et al. (2014) define an indicator as *the operational representation of an attribute of a given system, by a quantitative or qualitative variable, including its value related to a reference value*. In case an indicator relates to a criterion, an objective or a target, it may be referred to as a performance indicator. Fundamentally, indicators can be applied in three ways; as explanatory tools, pilot tools, or performance assessment tools. Application of indicators for performance assessment is widely regarded as the most important role of sustainability indicators (Shen et al. 2011; Hiremath et al. 2013).

2.6.1 Sustainability Assessment Indicators

Indicators[8] have been applied for sustainability-based technology assessment. Indicators can also be used for monitoring the progress towards or away from sustainability. Prior to identifying sustainability indicators for assessment, sustainability attributes of a system or technology should be identified. Within the water, wastewater and sanitation sectors, a range of socio, economic and environmental quality indicators have been used for decades to evaluate various systems (Lundin et al. 1999; Vleuten-Balkema 2003; Muga and Mihelcic 2008). Lundin et al. (1999) further suggest a set of criteria that can be considered when selecting indicators and these include;

- the indicators should be able to demonstrate a move towards or away from sustainability,
- should be applicable to a broad range (type and scale) of technological systems,
- have the ability to provide warning of potential problems,
- amenable to existing data,
- comprehensive and
- cost-effective.

In application of indicators for assessment of wastewater treatment systems, (Vleuten-Balkema 2003) further differentiates indicators according to categories i.e. functional, economic and environmental among others.

Functional indicators: define the minimal technical requirements of the solution. With reference to this research where management of organic waste streams is considered, indicators such as system adaptability, robustness or durability may be considered. Adaptability investigates the extent to which the system capacity can be adjusted or upgraded with reference to additional organic waste. Robustness checks ability of the system to cope with fluctuations in organic waste quantities. While, durability checks the system lifetime.

Economic indicators: commonly estimate investment costs**,** operation and maintenance costs accounting for the estimated lifetime of a system. In this category, the derived indicators with respect to the research could include life cycle costs of sanitation systems.

[8] Indicators are defined as a summary measure that provides information on the state of, or change in, a system (EPA 2011)

Environmental indicators: commonly check the optimal resource utilization, addressing water, nutrients and energy use. Furthermore, required land area, emissions to environment and potential resource recovery are some indicators options considered in this category.

Social–cultural indicators: although proven to be important, both social and cultural indicators are often hard to quantify and may not be addressed in certain cases. Examples of social-cultural indicators include social acceptance and institutional requirements etc (Vleuten-Balkema 2003). Waas et al. (2014) suggest that sustainability indicators have several complementary purposes in a decision-making strategy for sustainable development and in sustainability assessment. These purposes are supportive to the three sustainability decision-making challenges of interpretation, influence and information structuring. Thus, sustainability indicators assist in

- Structuring complexity and communicate information
- Operationalisation of sustainable development
- Social learning
- Demonstrate accountability and benchmarking
- Identification of knowledge and data gaps

Moreover, Waas et al. (2014) further point out that with reference to sustainability, certain dichotomies deserve attention since they touch upon important aspects of sustainability indicators and are in practice frequently the subject of discussion and controversy. The dichotomies include;

- Descriptive vs. normative
- Quantitative vs. qualitative
- Objective vs. subjective
- Community vs. expert
- Ex-ante vs.Ex-post

Descriptive indicators give a description of an actual situation while *normative* sustainability indicators compare an actual situation with a desired one. *Quantitative* indicators are based on *quantitative* data and provide information in a quantitative/numerical manner such as the life cycle costs for instance. While for *qualitative* indicators which are based on qualitative data provide information in a qualitative/non-numerical manner. Examples of *qualitative* indicators may include adaptability of sanitation systems.

The distinction made between the *objective* and *subjective* sustainability indicators is that *objective* indicators are sensed by instruments outside the individual such as, thermometers or counters that can be verified by others. An example where *objective* indicators were used in this research is during experimental analysis discussed in Chapter 5. *Subjective* indicators on the other hand are sensed only from within the individual by individual judgments and are often not verifiable by others through instruments but only verifiable through "*subjective*" explanations. Examples of these indicators include *perception* towards sanitation system which could influence system acceptability.

Community and *expert* sustainability indicators are essentially about who develops the indicators i.e. stakeholders reflecting a "bottom up" and/or *experts* reflecting a "top down" approach. In some cases "*hybrid*" or "*multiple* perspective" sustainability indicators are also considered. In this research a hybrid approach was adopted as detailed in Chapter 9. Finally, the *Ex-ante* and *ex-post* sustainability indicators go hand in hand with the ex-ante/ex-post sustainability assessment divide. *Ex-ante* indicators provide information for assessment of the effects of decisions in advance and support choices between various options before practical implementation. While *ex-post* indicators provide information after decisions are taken to assess or evaluate their practical implementation (Waas et al. 2014). An ex ante approach is considered in this research.

e) *In assessing the sustainability of sanitation system alternatives in this research, reference is made to a range of dichotomies of the sustainability indicators discussed. Although indicators could be considered "tailor-made" for the sustainability assessment of the system alternatives, reference is also made to indicators already applied in other studies to help check standardisation and incomparability often associated with tailor-made indicators. Moreover, to reduce subjectivity and ensure accurate measurement of indicators, clear rating scales were applied as indicated in the questionnaires used for eliciting necessary information attached in Appendix 5.*

In the field of sanitation and wastewater technology assessment, variable research assessing sustainability using indicators has been carried out. In some of the studies reviewed, the authors have attempted to describe sustainability from different perspectives or dimensions and in different scopes, contexts or wide ranges as summarised in Table 2-5.

Table 2-5: Summary of Studies on Sustainable Sanitation Technology Assessment Using Indicators

Publication	Description	Key Remarks
(Vleuten-Balkema 2003)	The selection of indicators in this study is based on literature review of related studies. The main focus is on using sustainability-oriented criteria for comparing and selecting wastewater technologies using modeling. The need for context-specific (knock out) criteria was cited although a framework for formulating the knock-out criteria is not provided. Five main criteria categories were considered and these included; economic, environmental, technology/functional, health, and sociocultural/institutional issues. In the analysis, the sustainability indicators are quantified through mass and energy balances, cost benefit analysis, and actor analysis, or indicated qualitatively.	Modeling qualitative and quantitative assessment for selecting sustainable wastewater treatment systems. • Application for different scales of sanitation systems. • Knock-out criteria for specific context is not provided
(Bracken et al. 2004)	In this study, focus is mainly drawn to using sustainability-oriented criteria for comparing and selecting sanitation technologies. The authors also acknowledge the need for context-specific criteria and suggest a list of criteria under the categories health, environment, economy, socio-culture, and technical function. Although the need for context specific criteria is mentioned, related analysis is not provided.	Proposed multi-criteria analysis for sustainability assessment of sanitation technologies. • Framework for formulating the knock-out criteria was not proposed.
(Palme et al. 2005)	In this study, selection of sludge handling and wastewater treatment systems was carried out with the help of sustainable development indicators (SDIs). Selection of the criteria for evaluation of the sanitation options was carried out by researchers in consultation with Stockholm Water Company (SWC). Prior to using multi criteria analysis (MCA) for assessment of sustainability, life cycle assessments (LCA), risk and uncertainty in addition to economic assessments were carried out. The results from these assessments were used as inputs for ranking technical options of sludge handling by use of MCA. The MCA included assessment of the different technical options and aspects of sustainability and weighting. The resulting SDIs reflected economic, environmental, technical and social aspects of sustainable development of sludge handling systems.	Using multi-criteria analysis to evaluate sludge handling and wastewater systems. • Selection of indicators involved intended stakeholders. • Application of indicators is for internal decision making.

	After the MCA, sustainability development indicators (SDI) were developed for internal use by SWC to support internal decision making and management by objectives.	
(NETSSAF 2006)	The criteria presented in this study were the outcome of a series of consultations and meetings of a working group focused on network development of sustainable approaches for large scale implementation of sanitation in Africa (NETSSAF). Although reference was made to different research, a huge emphasis was on the criteria developed by (Bracken et al. 2004). As such, criteria categories considered were health, environmental and resource, technical and operational, financial and economic criteria, social, cultural and gender. The criteria enable households/authorities to decide which sanitation option is most suitable given the profile of their communities. It was also emphasised that the criteria list given was not context specific but meant to give a comprehensive overview. Thus, for any given situation locally relevant criteria would have to be identified from the general list. Thereafter, merging of the non-context specific criteria with the framework conditions of typical settlements would be carried out and a complete list of feasible sanitation systems for the given conditions developed.	Multi- criteria are provided to analyze sanitation technologies. • Contextualization was carried out by merging the criteria with information concerning framework conditions of typical settlements for a given condition. • Application is intended for developing countries, particularly Africa.
(Muga, and Mihelcic 2008)	The study set out to investigate the sustainability of different wastewater treatment technologies for plant capacities of less than 5 million gallons per day. Indicators were used for the sustainability assessment. Selection of indicators and evaluation of particular technologies was dependent on the geographic and demographic particulars of a community. The set of indicators selected were incorporated under environmental, societal, and economic sustainability themes. The overall results of this study showed that there were varying degrees of sustainability with each treatment technology.	Multi-criteria indicators are proposed to analyse sustainability of wastewater treatment technologies. • Selection of indicators was dependent on local context, although each technology already showed different degree of sustainability.
(Van Buuren 2010)	A participatory multi- criteria decision analysis (MCDA) method is adopted for selection of drainage and sanitation systems in developing countries, with a particular focus on unplanned areas in Ho Chi Minh City, Vietnam. Selection of criteria used in the assessment was based on stakeholder input and detailed literature	Multi- criteria decision approach used for selection of drainage and sanitation systems. • Selection of criteria based on stakeholder input and detailed

	review on available sets of criteria from related studies. Moreover, criteria selection was informed by reference to requirements for criteria sets suggested for MCDAs. Also, a simple criteria selection framework was considered, where criteria were screened and compared prior to final selection. Key criteria categories considered were technical functionality, health, environment, economic and financial, social and cultural. For each of the criteria categories selected, indicators were assigned for fulfillment of criteria. A tool for technology/system selection, **SANCHIS** was derived from this study. The study recommended that **SANCHIS** method for drainage and sanitation decision making should be applied in a *flexible* way with respect to setting, form, stakeholder involvement.	literature review on available sets of criteria. • A simple framework for criteria selection considered reference to criteria set requirements suggested in MCDA. Moreover, screening and comparison of criteria was also incorporated to enable final selection of criteria set. • **SANCHIS** planning tool was developed
(Nayono 2014)	The main goal of the study was to contribute to the development of a methodology for a sanitation planning tool, with sustainable technology as the main outcome. Bearing in mind that sustainability is a multi-dimensional concept, a set of sustainability-based technology assessment indicators were developed based on the integrative approach for sustainable development(Kopfmüller et al. 2001). Selection of the set of indicators considered key factors; • *the minimum requirement a technology should fulfill for sustainable development* • *the relevant problems to be addressed in developing countries i.e. financial, society mind-set, energy crisis etc.* • *the data availability in developing countries, particularly in the project area* The **SusTA** planning tool developed in this study also recommends a set of sustainability-based technology assessment indicators derived from the Helmholtz Concept. Moreover, the indicators are equipped with a modifiable rating scale, which can accommodate the local concerns and needs.	The Helmholtz integrative approach for sustainable development was referred to. • Selection of the set of indicators considered key factors and • The technology assessment indicators were derived from the Helmholtz integrative concept. • **SusTA** planning tool was developed

Source: Author

The review summarised in Table 2-5 highlights key issues related to the sustainability assessment in wastewater and sanitation related research:

- Generally for most of the studies, the set of indicators selected are context specific and often applicable only for the particular case study. The fact that aspects such as environmental, social, and economic landscapes are site-specific implies that indicators with the similar values may have different implications in different regions. An example could be that measurement of land requirement in different locations (rural, peri- urban or urban) may not have a similar impact. From one domain to another, there can be different factors influencing land requirement and this could be related to settlements in the area, ownership etc. To counter the limitation related to specificity, Murray et al. (2009) suggest that indicators should be designed with reference to local impact factors, which are basically a type of benchmark that clearly reveal not just a raw number as a result but how the number manifests itself locally. However, in the absence of such local impact factors, applicability of similar indicators for other areas may be achieved if study areas are similar.
- Furthermore, with reference to most technology assessments, there appears to be a general notion that certain technologies/ systems considered are sustainable while others are not and that the task of researchers and technicians is to evaluate and compare different techniques. While following such notions, there is a possibility of overlooking the importance of the local context and yet context is crucial when assessing the sustainability of sanitation related technology (Hoffmann et al. 2000).

Moreover, from the review it is evident that no set of indicators can be applicable for all cases, especially since context has to be considered with regards to sustainability assessment. As noted in the studies reviewed, the set of indicators are very contextual and only applicable for a particular study area although with necessary modifications, application of similar indicator sets could be considered in similar areas.

f) *Although development of a generic indicator set is not the goal of the study, the need to have widely applicable indicators for assessment would enhance future planning and implementation of the integrated sanitation system approach proposed. As such, this research takes into consideration reference to the integrative concept of sustainability in addition to detailed review of related literature and a stakeholder participatory approach to inform indicator selection. By combining these approaches, applicability of indicator sets would not be limited to specific case study areas but allow for minor modifications to be included so that further application of the indicator sets can be considered in similar study areas.*

g) *With reference to the possibility of overlooking the local context when comparing or evaluating technologies, this research considers inclusion of a stakeholder participatory approach in sustainability assessment of system alternatives as a measure to integrate the local context.*

In summary, this review Chapter points out that although the concept of integrated sanitation has been in existence for more than two decades, it is context specific and as such the definitions of integrated sanitation may be variable. In the context of this research, the integrated sanitation approach considers interventions designed for improved management of organic solid waste, sewage and faecal sludge, animal dung and wastewater effluent reuse. Thus, the approach which is based on the environmental sanitation concept focuses on combined management of specific waste streams in sanitation systems, with the view of integration of technology to environmental, economic and social conditions. The approach which considers a holistic stance of sustainability further emphasises resource recovery from management of the organic waste streams. As such, the integrated sanitation systems suggested in this research are considered a possible solution to management of the specific organic waste streams in peri-urban and urban areas of Uganda.

A review of the existing environmental sanitation approaches which were developed based on the *Bellagio principles* of sustainable development highlighted certain gaps related to the clear definition of sustainable sanitation technology and the absence of a procedure for which comprehensive sustainability assessments can be carried out. Therefore, by carrying out a holistic feasibility assessment of integrated sanitation systems, this research intends to avail necessary information to fill the gaps identified. The findings from the holistic feasibility assessments are expected to inform the sustainability assessment of sanitation systems.

Furthermore, reference to the Helmholtz integrative concept of sustainable development in addition to reference to existing criteria and indicator sets relevant for sanitation systems is expected to further inform the sustainability assessment of integrated sanitation systems. Moreover, by engaging a participatory approach throughout the assessment process, it is expected that further information and guidance for the sustainability assessment of integrated sanitation systems can be obtained. This research will then conclude with the suggestion of a planning framework for the integrated sanitation system approach. It is anticipated that the planning framework suggested in this research can be used as a guide in case integrated sanitation systems are considered for different domains in urban areas of Uganda and possibly Sub -Saharan Africa as a whole.

Given that the integrated sanitation system approach is considered a possibility for various domains in urban areas of Uganda and Sub-Saharan Africa, an understanding of the sanitation situation in the region and appreciation of available sanitation technology options was deemed necessary. Chapter 3 gives a detailed discussion of these aspects.

3 Sanitation Status and Technology Options for Urban Areas in Sub Saharan Africa

Chapter 3 *presents the status of sanitation in urban areas of Sub-Saharan Africa and discusses the key impacts of poor sanitation while citing the main hurdles to sanitation coverage in the region. The second part of the chapter discusses the various sanitation systems used for management of key waste streams discharged in to the environment. Finally, the chapter concludes with the identification of entry points for integrated sanitation systems in urban areas of Uganda.*

3.1 Sanitation in Urban Areas of Sub-Saharan Africa

Provision of sanitation for urban areas in Sub-Saharan Africa is a core precondition for development. Unlike in other parts of the world, urbanisation in Africa has not been associated with improved human development. Instead 63% of the urban populations in Africa still live in slums characterized by overcrowding, inadequate housing, insecure tenure and lack of access to water and sanitation (UNECA 2013). Often the case infrastructure development does not match the rate of urbanisation and as a result, sanitation challenges are prevalent in urban areas, especially in the urban poor areas (MoWE 2016; Lüthi et al. 2011b). The mere fact that most of the slum or informal settlement dwellers do not own land or houses further implies that there is no incentive to invest in sanitation facilities or services.

Generally, urban sanitation coverage in Sub-Saharan Africa has increased by only 1% over the last 20 years and the number of people without access to improved sanitation has grown to at least 684 million people as shown in Figure 3-1 (Hawkins et al. 2013; Cross, and Coombes 2014). Despite this slight increase in sanitation coverage, huge disparities in access to improved sanitation in urban areas exist due to the variable income levels. Statistic indicate that the lowest quintile have around 50 percentage points less coverage than the richest (AMCOW 2011). Moreover, further variability exists in urban sanitation coverage at national level, with Uganda for instance registering 63.4 % access to private improved sanitation for the urban population (MoWE 2016). Reflecting on such dynamics, it is clear that increasing the provision of sanitation services to the urban multitudes is a challenge that urgently needs to be addressed. Both access to and the quality of sanitation will need to increase at a much faster pace and on a larger scale than in the past if the growing demand influenced by urbanisation is to be met. The mere fact that urban areas are often characterised by high population densities implies that poor sanitation could quickly result in negative impacts on public health, human livelihood and also lead to degradation of the environment (Peal et al. 2010; Parkinson et al. 2014).

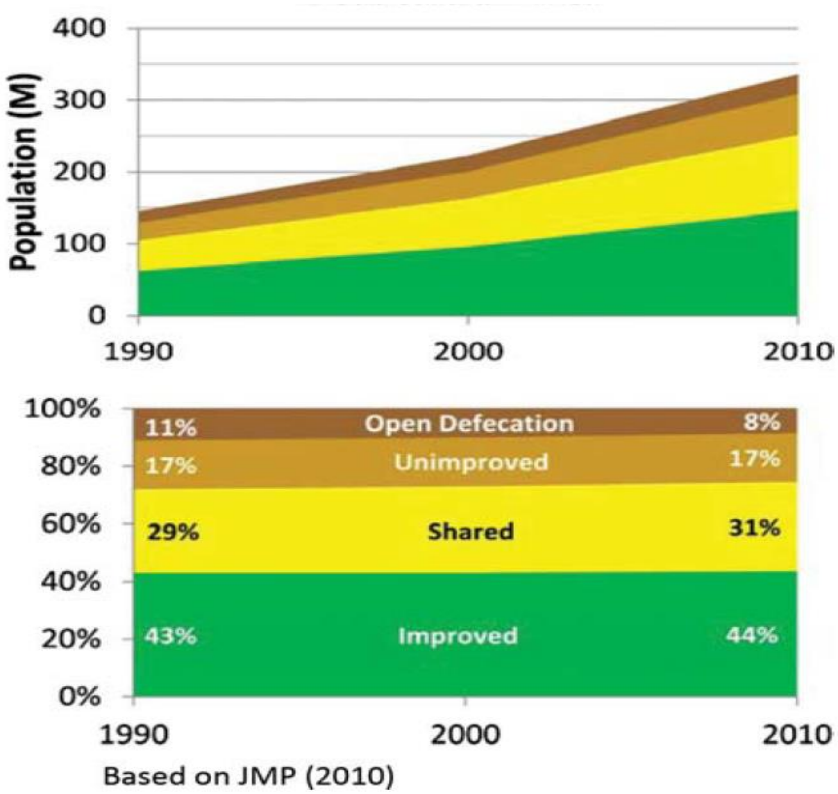


Figure 3-1: Urban Sanitation Coverage in Sub-Saharan Africa
Source: (Cross and Coombes 2014)

3.2 Impacts of Poor Sanitation

In urban settings of developing regions such as Sub-Saharan Africa, untreated wastewater and faecal matter has been known to end up in rivers, lakes or wetlands. Discharge of these waste streams is associated with limited sewerage coverage accounting for only about 10% and the fact the onsite sanitation systems are commonly utilised. Discharge of faecal matter and wastewater to water bodies occurs either intentionally or indirectly through washing away by rainwater and flooding. Also, wastewater and waste maybe indiscriminately disposed into public drainage systems, choking drainages especially during rainy season (Lüthi et al. 2011b; BMZ 2009). Such practices result in the spread of diseases posing more hygiene risks in addition to contamination of water bodies, leading to a multitude of health related and livelihood impacts briefly discussed.

3.2.1 Impact on Human Health

Poor sanitation caused by utilisation of inadequate sanitation facilities and poor hygiene among others often results in transmission of diarrhoeal diseases and chronic worm infectious diseases through the faecal-oral route (Lüthi and Parkinson 2011c; Lüthi et al. 2011b). Recent global facts from UNICEF indicate that diarrhoeal diseases still account for 9 % of all deaths among children under the age of five and yet the disease is highly preventable.

Despite the significant drop in diarrhoeal related deaths by about 57 % since the year 2000, much more needs to be done since about 526,000 death were still registered in 2015 alone (UNICEF 2016). Geographically, Africa and South Asia account for over half the cases of diarrhoeal related childhood deaths, justifying the impetus to adapt necessary changes to reduce the mortality rate. In relation to disability adjusted life years(DALYs), (Lüthi et al. 2011b) suggest that the impact of diarrhoea in all age groups equates to 73 million DALYs. This figure is without the inclusion of additional health burden due to malnutrition caused by diarrhoea and other "neglected" tropical water, sanitation and hygiene related diseases. When all the related diseases are included, an overall estimation of 112 million DALYs can be linked to diarrhoeal diseases, emphasising the gravity of the situation. As such, provision of hygiene education, clean drinking water and basic sanitation are some of the tried and tested measures to fight diarrhoeal related diseases and its related devastating consequences (BMZ 2009; Lüthi et al. 2011b; UNICEF 2016)

3.2.2 Pollution of Water Resources by Nutrients

Discharge of poorly treated wastewater effluent and residues from sanitation facilities into water bodies results in pollution. Such discharge is responsible for eutrophication caused due to the presence of excessive amounts of nutrients such as nitrogen, phosphorus and at times organic matter in the effluent. In the developing world, it is estimated that more than 90% of sewage is discharged directly into rivers, lakes, and coastal waters without treatment of any kind (ECA 2016; Lüthi et al. 2011b). Noteworthy is that agricultural runoff is also a source of nitrogen and phosphorus nutrients although discharge of untreated wastewater is considered a major contributor to eutrophication in most Sub-Saharan African countries. That said, the presence of such nutrients in freshwater bodies in excessive amounts encourages growth of algae which may alter aquatic eco-systems due to clouding of water surfaces. Such alterations may result in elimination of fish species and vegetation eventually decreasing oxygen levels in deeper waters and increasing sediments (ECA 2016; Lüthi et al. 2011b). Therefore, for regions such as Sub-Saharan Africa, proper wastewater treatment prior to discharge to water bodies is an imperative measure among others to reducing eutrophication.

Examples of stringent measures to check eutrophication can be seen in Europe where water bodies such as the Baltic Sea are closely monitored. In so doing, all countries neighboring the Baltic Sea and discharging into it are expected to ensure that treatment of wastewater results in reduction of phosphorus content to 0.5 mg/l prior to discharge. Moreover, measures to limit total content of phosphorus in laundry detergents are suggested (ECA 2016).

3.2.3 Economic Impacts

Economically poor sanitation related Illnesses have a direct impact on household finances since a portion of the finances would be required to pay for primary healthcare and loss of working days due to sickness. In case chronic infections from worm infestation occur, then long term impacts on other activities such as education and physical performance are affected by illness. Such long term illnesses may affect the productivity of other family members as well (Lüthi et al. 2011b, 2011b; Hutton 2012, 2015).

Inadequate sanitation facilities and unhygienic provisions are known to significantly affect girl child school attendance. Girls are reluctant to attend school and parents are hesitant to send them in the absence of safe private toilets facilities for menstrual management (WaterAid 2011; Lüthi et al. 2011b). Furthermore, for persons who depend on physical strength to earn a living, poor state of health caused by malnutrition or diarrhoeal diseases can hamper their livelihood resulting in inequalities within society. Such scenarios can also result in social effects such as, affecting esteem which could in turn cause seclusion and even depression thus, indirectly impacting economic activities.

Therefore, irrespective of the level at which poor sanitation occurs i.e. at household, community or city levels, the related impacts do not only result in poor health but cause pollution of the environment and water resources which may directly or indirectly hamper economic development (Lüthi et al. 2011b). These cross cutting impacts of poor sanitation justify global concerns to ensure improved sanitation access and further affirm sanitation as a basic human right. With reference to the low urban sanitation coverage in the region and particularly Uganda, understanding of the challenges met in sanitation provision is imperative to inform any related future plans for improvement.

3.3 Challenges to Urban Sanitation in Africa

Although at national level sanitation coverage in urban areas within Sub-Saharan Africa may vary, the challenges met in provision of sanitation in the region are generally similar. Provision of sanitation is met by hiccups related to lack of priority setting and political will, inadequate institutional framework and legal requirements, inappropriate financing schemes and lack of capacity/expertise as discussed.

3.3.1 Priority Setting and Political Will

Lack of political will at governmental level has led to low prioritization of sanitation in Sub-Saharan Africa as a region. Historically, sanitation and hygiene related topics were relegated to back seat positions as priority was given to other topics such as energy, security etc. This was even evident in allocation of funds at global level. As International aid rose steadily since the mid-1990s, the share of aid to water supply and sanitation was generally low (Tearfund and WaterAid 2008). For instance during the financial year 2010/11, global aid to water and sanitation accounted for only 6% (OECD 2008). Despite the low aid contribution to water and sanitation sector, statistics indicated gradual increase over the years as shown in Figure 3-2. At country level, findings documented in the GLAAS report of 2014 showed that government budgets and expenditures for water, sanitation and hygiene (WASH) were gradually increasing. However, there still remains a huge financing gap between the budget and plans. About 80% of countries documented in this report indicated insufficient financing for the water and sanitation sector (GLAAS 2014).

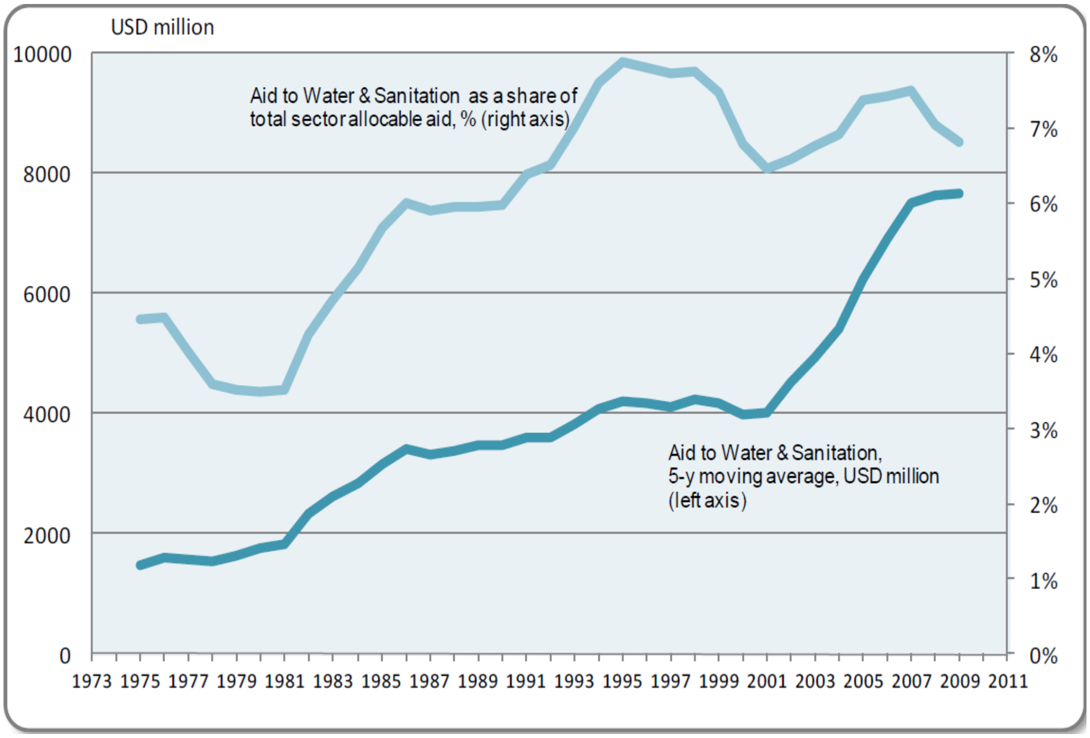


Figure 3-2: Trends in global aid to water and sanitation
Source: (OECD 2013)

Politically, there has been little incentive by governments to deal with the difficult subject of liquid and solid waste management. This is partly because the pressure on politicians to focus on sanitation issues is often low, especially since the neediest have the least political power. As such, policy and institutional responsibility for sanitation is often unclear, fragmented or absent (WaterAid 2011; EAWAG-SANDEC 2008). The combination of these issues additionally results in conflict amongst organizations dealing in sanitation and this has led to improper allocation of funds or mismanagement, eventually stifling sanitation provision.

Therefore, an overarching vision and political will set at the highest level of a nation is certainly a key to successful sanitation promotion. Such an initiative allows for recognition of challenges and articulation of broad objectives, creating an enabling environment. A practical example of the positive impact of political will can be seen in Indonesia. Local municipality leaders (Mayors) spear headed sanitation initiatives and this eventually attracted the national government attention which resulted in development of a national sanitation program (WSP 2011). In other areas political support in promotion of sanitation through advocacy messages and other mechanisms of raising public awareness have been successful in boosting sanitation at various levels (EAWAG-SANDEC 2005).

3.3.2 Inadequate Institutional Framework

Institutional framework refers to a set of formal organizational structures, rules and informal norms for service provision. In the field of water supply and sanitation, this involves outlining the responsibilities of water services institutions for various aspects of the water sector, including the following areas; water resource management, allocations, monitoring and licensing water services provision, regulation, contracts with service providers and consumer charters (IEES 2008). Institutional framework is informed by key principles which include;

- Requirement for a clear definition of roles and responsibilities;
- The separation of regulatory and operational responsibilities;
- Local governments responsible for ensuring water & sanitation services provision;
- Flexibility in terms of scale and type of water & sanitation services provider;
- The private sector and civil society have a role to play;
- Management must take place at the appropriate level;
- Building on existing capacity;
- The need for transformation and policies sensitive to gender differences

Lack of sound institutional frameworks is the root cause of many failures in service delivery and a major cause of failed sanitation provision. In most cases, the available institutional frameworks in developing countries are considered monopolistic and lacking in transparency. As such, the needs of most vulnerable segments of the population are often neglected as the powerful role of non-governmental organizations (NGOs) and the private sector maybe ignored (EAWAG 2005). Usually, existing national or local standards are based on those developed in industrialised countries. However, since respective conditions in developing and developed countries vary widely, the national standards adopted from developed nations are often not representative and inappropriate for developing nations. In scenarios where such standards or legal requirements are present in theory, they may not be applicable because of the related expenses for implementation and weak enforcement in developing countries (EAWAG-SANDEC 2005; Cross and Coombes 2014).

Absence of context specific institutional frameworks further implies existence of weak enabling environment for implementation of sanitation initiatives. Recent emphasis on incorporating multi stakeholder participation and multi sector involvement are attempts to boost institutional framework development while including the local context. The importance of stakeholder participation and institutional frameworks has been reflected in various sanitation approaches and planning tools discussed in Chapter 2.

3.3.3 Inadequate Legal Requirements

Often the case, existing policies at national level are counterproductive to creating a supportive environment for sanitation. For example, policies may focus too much on water supply at the expense of wastewater management and existing subsidies may favor centralized systems in middle and high-income communities.

This could imply that informal settlements within the urban areas and other areas where decentralized solutions are prominent are left out in terms of legal requirements. Although most countries generally have basic wastewater management policies and supporting legislation governing water-resource protection, policies are generally not specific or well defined (EAWAG-SANDEC 2008). Ideally the policies should reflect the needs and preferences of people however, this is usually not the case in most developing countries because the policies are very ambitious and hard to fully translate to action. Thus, despite the existence of policies, the implementation process is flawed in many ways. Lack or inadequate financing for sanitation, and serious lack of technical capacity further enhance this flawed process (EAWAG-SANDEC 2008; Ekane et al. 2016).

The fact that most cities in Africa are characterized by existence of informal, unplanned and illegal settlements makes it almost impossible to apply the already insufficient legal framework to guide sanitation project implementation. The very nature of certain slums often considered temporal settlements for the occupants influences the reluctance to put in place adequate sanitation facilities. Moreover, interested private or public entities may not have the mandate to implement or operate sanitation projects in such areas (EAWAG-SANDEC 2008).

3.3.4 Inappropriate Financing Schemes

In most Sub-Saharan African countries today, investments in solid and liquid waste management programs are financed largely by tax revenues and government borrowing. These public funds however fall short of the required level of investment to cover the rapidly growing demand for sanitation services. Moreover, competition for the meager finances with other sectors like security, education, leaves local governments financially strapped and dependent on foreign aid. This has resulted in a common practice where donors and NGOs fund investments directly, often bypassing local government budgets. The aftermath of such practices implies that local governments' lose control over sanitation programmes and this affects transparency and information dissemination, further complicating planning and efficient budget allocation. Although some countries have attempted to check this habit, the tendency to limit local authority involvement due to NGO dominance is still common (Mehta and Mehta 2008; Cross and Coombes 2014).

While foreign aid has been helpful in achieving various programmes especially in Africa, the practice is not without its qualms. Foreign aid supported sanitation programmes have also been marred with higher costs in remitting attained loans and import of unfamiliar or at times inappropriate technologies for local contexts. The latter leading to rejection of sanitation facilities/programs in some cases (UN-HABITAT 1996).

Despite these hiccups, mobilisation of local private capital for liquid waste management systems has been extremely challenging. This is because private capital is limited and implementation of certain sanitation systems[9] may require high level commercial risks and high initial investment. In addition, wastewater and solid waste management have to compete for the meager private resources with other sectors yielding higher returns on investments such as energy. Very gradual and limited private capital investments in sanitation are often deterred by the assumption that users of sanitation facilities do not have the means to pay for the service. As such, strongly subsidised unsustainable sanitation projects have been implemented in certain areas, missing the point of access to improved sanitation (EAWAG-SANDEC 2008; Andersson et al. 2016b).

3.3.5 Capacity and Expertise Requirement

Often the case lack of local expertise and capacity has hindered implementation of sanitation projects in developing nations. Local government abilities to develop strategies and plans for urban environmental infrastructure are usually restricted by central governments. As such, local governments depend on central governments to financially facilitate local budgets which in turn influence local government activities such as planning for sanitation, technical implementation among others (UN-HABITAT 1996;Cross, and Coombes 2014). Such situations could be ignored when the urban sector was rather small however, with the increasing populations and rapid urbanisation, the centralised approach is becoming less relevant. Moreover, there is ardent need for increased expertise and capacity to satisfy the various settlement clusters in urban areas. The multi-faceted nature of water, sanitation and hygiene sector means that a wide range of different disciplines and skills is required to improve sanitation and hygiene provision. As such, expertise in fields of planning, environmental engineering, waste treatment and management, social aspects, gender involvement and policy formation among others are necessary not only at the central government level but should trickle down to local governments. Building capacity in mentioned fields of expertise through trainings, awareness raising and implementing necessary reforms in the sanitation field could also improve much required expertise at local level (Cross and Coombes 2014).

Already experience shows that centralised approaches, particularly with regards to liquid waste management has been poor at reaching peri-urban areas and has not been responsive to local needs and resource availability (EAWAG-SANDEC 2008; Gutterer et al. 2009). Thus, engaging in capacity building to enable implementation of other appropriate sanitation options such as **EcoSan** or integrated sanitation approaches proposed in this research could be relevant to counteract the gap created by inadequacy of centralised approaches in other urban areas.

[9] Sanitation system; consists of a multi-step process in which human excreta and domestic sewage are managed by a sequence of technologies from the point of generation to the point of reuse, recycling or safe disposal Lüthi et al. (2011b)

Having recognised some of the main hurdles to sanitation provision in the region, it is no doubt that provision of sanitation solutions will additionally require recognition of a variety of typical urban settings and an innovative approach to linking them to appropriate sanitation systems. Therefore, incorporation of sustainability in sanitation is considered a necessary catalyst for urban development. Consideration of sustainability in sanitation is no longer considered optional but is a requirement and this notion can further be justified by the existence of an own sustainable development goal (**SDG**) for sanitation i.e. **SDG 6**.

SDG 6 seeks to *ensure availability and sustainable management of water and sanitation for all.* Specifically, targets **6.2** and **6.3** of **SDG 6** set out to accomplish the "unfinished business" from the **MDG** era. **Target 6.2** sets out to *achieve adequate and equitable sanitation and hygiene for all, and end open defecation while paying special attention to the needs of women, girls and those in vulnerable situations.* While **target 6.3** sets out to *improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and increasing recycling and safe reuse by x% globally.* For both targets, **WHO** proposed indicators for assessment and these include; *percentage of population using safely managed sanitation services* for target 6.2. While for target 6.3 *percentage of wastewater safely treated* is the suggested indicator. Both indicators portray all-inclusive characteristics, rather than the technology specific improved sanitation indicators used in the **MDG** era(Hossain 2015; UN 2015).

3.4 Sustainability in Sanitation

Sustainable sanitation is not limited to a single technology or specific sanitation system design, but is considered an approach where a broad set of criteria needs to be taken into consideration in order to achieve universal and equitable access to services over the long-term in a particular context (Andersson et al. 2016b). Originating from the common definition of sustainable development by the Bruntland report(refer to Chapter 1), " Lüthi et al. (2009) refer to *"urban sustainable sanitation as one that meets the basic sanitation needs of all population segments of the present generation within a city/town(principle of equity) without compromising the present and future generations living inside and outside of the city to meet their own needs" (Lüthi et al. 2009).* Sustainable sanitation considers sanitation holistically while additionally promoting a closed loop approach. In so doing, waste is recognised as a "resource" rather than as a nuisance in the conventional approach (SuSanA 2008; Andersson et al. 2016a).

Sustainable sanitation in the urban context has resulted in development of a number of concepts and visions attempting to define what future cities or urban areas could look like. Some of these concepts have conceived the so-called "Eco-Cities" or "Sustainable Cities" currently planned and implemented mostly in developed nations such as China, South Korea Germany, Brazil, and Netherlands among others. In general, the "Eco-City movement", "Sustainable Cities", "Permacity", promote the concept of "*Environmentally Sound Technologies*" with the aim of contributing to the (re-) development of the urban environment according to the concept of sustainability.

A sustainable sanitation system is defined as one which in addition to being economically viable, socially acceptable, technically and institutionally appropriate should protect the environment and natural resources (SuSanA 2008). Planning and implementation of such sanitation systems is guided by the *Bellagio principles* mentioned in Chapter 2. Although in most cases sanitation systems are designed with sustainability aspects in mind, practice shows that too often, failure in implementation may result because some of the criteria are not met. The discourse related to sustainable sanitation highlights that fact that there is probably no system which is absolutely sustainable. This is mainly because local context plays a big role in influencing the sustainability of a sanitation system. The local context is defined by the existing environmental, technical, socio-cultural and economic conditions (SuSanA 2008; Lüthi et al. 2009). Thus, a "one size fits all" approach does not exist as far as sustainable sanitation systems are concern. Instead, sustainable sanitation concept is more of a direction rather than a stage to reach (SuSanA 2008; Lüthi et al. 2009; Andersson et al. 2016a). Bearing this in mind, appreciation of the sanitation systems commonly used in Sub-Saharan Africa was deemed prudent in this research. However, knowledge of the waste streams or inputs to the systems is crucial to informing sanitation systems considered.

3.5 Waste Streams in Urban Areas of Sub-Saharan Africa

The major waste streams into the environment in urban areas of developing countries such as Uganda are excreta, wastewater and solid wastes (Kulabako et al. 2007; Paterson et al. 2007; IRC 2010). These waste streams have varying characteristics depending on the source and interaction with the environment. Pollution from the various waste streams is a result of pathogens, nutrients, micro pollutants and other trace organics in the waste (Paterson et al. 2007; Metcalf and Eddy 2004). Understanding the components of the waste streams is important in applying technology to overcome the pollution challenges in the urban environment.

Excreta

Excreta consist of urine and faeces that is not mixed with any Flush water. Though small in volume, excreta are concentrated in both nutrients and pathogens. Depending on the quality of the faeces, it has a soft or runny consistency (Tilley et al. 2014; IWA 2006).

Wastewater

Generally refers to all water used for domestic activities i.e. *greywater* and *black water*.
Grey water is the total volume of water generated from washing, laundry, bathing etc. While *black water* is the mixture of urine, faeces and flush water along with anal cleansing water and or dry cleansing materials (Gabert et al. 2012; Tilley et al. 2014). Wastewater composition is a function of the uses to which the water was submitted. These uses and the form with which the wastewater was managed/treated varies with climate, social and economic situation and population habits (Marcos von Sperling 2007). Table 3-1 gives a summary of characteristics of excreta and grey water compiled by Katukiza (2014).

Table 3-1: Characteristics of Faeces, Urine and Grey water: Loading Rates and Concentration

Parameter	Loading rates				Concentration			
	Unit	Faeces	Urine	Greywater	Unit	Faeces	Urine	Greywater
Organic matter								
COD	g/(ca.d)	37-63	10.0 - 12.0	7-102	g/L	10–50	4–11	0.35-0.78
BOD_5	g/(ca.d)	14-33.5	5.0-6.0	26-28	g/L	n/a	4	0.21-0.45
Nutrients								
N	g/(ca.d)	0.3-2.0	3.6-16	0.1-1.7	g/L	1.8-14	1.8-17.5	6.7-40
P	g/(ca.d)	0.3-0.7	0.4-2.5	0.1-2.2	g/L	2.2-4.1	0.2-3.7	0.4-31
K	g/(ca.d)	0.24-1.3	2.0-4.9	0.2-4.1	g/L	2.15-4.1	0.7-3.3	8.8
S	g/(ca.d)	0.2	0.6-1.3	0.5-7.7	g/L	-	1.2-2.6	72
Microorganisms								
E. coli	cfu/(ca.d)	$1x10^{8d2}$	-	$6.3x10^{9d1}$	cfu/100mL			$2x10^{0}$-$3.5x10^{5a}$ $3.8x10^{6}$-$8.5x10^{7b1}$ $1x10^{8}$-$1.4x10^{9b2}$ $7.5x10^{3}$-$2.6x10^{5c}$
Total coliforms	cfu/(ca.d)	-	-	-	cfu/100mL	-	-	$2.3x10^{3}$–$3.3\ x10^{5}$

Source: (Katukiza 2014)

Solid Waste

Waste is mainly a by-product of consumer-based lifestyles that drive much of the world's economies. Solid waste could consist of any garbage or refuse, sludge from a wastewater treatment plant and other discarded material from community, industrial, commercial and agricultural operations among others. In urban areas, it is often the mandate of local governments to manage solid waste. Uncollected and poorly managed solid waste can contribute to local flooding during rainy seasons, air and water pollution, eventually impacting public health. In most urban areas the management of municipal solid waste (**MSW**) is therefore an intensive service which requires human and technological resources through the whole service chain. **MSW** is viewed as a component of the environmental management process which has direct bearing on a city's attractiveness and its social, economic and political development (World Bank 2012; Simelane and Mohee 2012).

Globally, organic waste still accounts for the largest portion of solid waste contributing about 46%. Composition of **MSW** mirrors consumption patterns, eating habits, social structure, level of economic development, geographical location, energy sources, and climate of a particular population. As urbanisation in nations increases and populations become wealthier, the **MSW** composition also varies with the consumption of inorganic materials (plastics, paper, and aluminum) increasing and the relative organic fraction decreasing.

Hence, it is not unique that low and middle-income countries have a high percentage of organic matter in the urban solid waste stream which accounting for 40-85% of the total **MSW**. In Africa, organic waste contributes 57% of the total waste composition (World Bank 2012). Moreover, a study by Okot-Okumu (2012) shows main cities in East Africa, including selected main towns in Uganda registered organic waste composition of at least 70% the total waste as shown in Table 3-2.

Table 3-2: Solid waste composition in Major cities in East Africa and Selected Towns in Uganda

Waste composition (%)	Dar es Salaam	Moshi*	Kampala#+	Jinja	Lira	Nairobi*
Biowaste	71	65	77.2	78.6	68.7	65
Paper	9	9	8.3	8	5.5	6
Plastic	9	9	9.5	7.9	6.8	12
Glass	4	3	1.3	0.7	1.9	2
Metal	3	2	0.3	0.5	2.2	1
Others	4	12	3.4	4.3	14.9	14
kg/cap/day	0.4	0.9	0.59	0.55	0.5	0.6
Percent collection	40	61	60	55	43	65
Population	3,070,060	183,520	1,700,850	91,153	107,809	4,000,000
Population paying for collection (% of total population)		35	ND	ND	ND	45

ND: Not Determined
Source: (Okot-Okumu 2012)

As already highlighted in Table 3-2, urban areas in Sub-Saharan Africa consist of a cocktail of formal and informal settlement. Moreover, the various waste streams commonly discharged in to environment have to be managed. As a result, a mixture of different technologies or subsystems based on different approaches can form the sanitation system in these areas**.** Some of the sanitation system options may include; *centralised* and *decentralised, conventional* and *closed-loop*, *high-tech* and *low-tech*, *separated* or *combined* treatment of flow streams as well as *traditional* and *innovative* (IWA 2006). With reference to such a breadth of system options**,** Section 3.6 discusses some of the sanitation systems used in urban areas of developing nations.

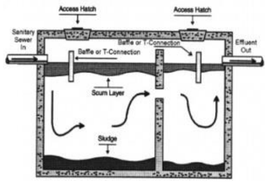
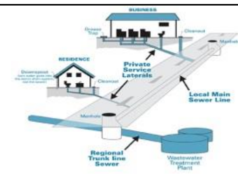
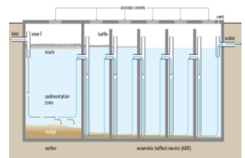
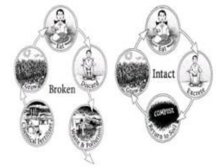
3.6 Sanitation Systems

Sanitation systems are a combination of technologies/processes through which the products flow and are also referred to as sanitation "hardware"(EAWAG-SANDEC 2008). A sanitation system contrary to a sanitation technology[10] considers all components required for the adequate management of considered waste streams i.e. human excreta, solid waste, and storm water etc. Operations and activities involved in managing the waste streams through a sequence of technologies are among the various aspects to consider with regards to a sanitation system.

Other aspects such socio-cultural, economic and environmental can also not be ignored. As such, sanitation systems are often described with reference to value chains which with regards to liquid waste management consider five main components or functional units. Table 3-3 shows the five value chain components of a sanitation system i.e. user interface, containment/collection, conveyance/transport, treatment and disposal/reuse. Moreover, respective technology examples for the components as included (Tilley et al. 2014). Sanitation systems can be classified based on location, processes involved, context of use as well as structure stability to mention but a few. However, often the case discussions regarding sanitation system classification are based on location i.e. "on or off" site and the context of use. Table 3-4 gives a summary of some of the common sanitation system types based on location and context of use. These sanitation systems are also used in urban settings of most low and some middle income regions such as Africa.

[10] Sanitation technologies are the specific infrastructural configurations, methods or services designed specifically to contain, transform or transport products to another process, point of use or disposal Tilley et al. 2014.

Table 3-3: Liquid Waste Management Value Chain

User Interface	Collection & storage/treatment	Convenyance	(Semi-) Centralized Treatment	Use and or/Disposal
				
• Dry Toilet • Urine Diverting Dry Toilet • Urinal • Pour Flush • Urine Diverting Flush Toilet	• Single pit • Single VIP • Dehydration vaults • Septic tank • Composting chamber • Anaerobic baffled reactor • Anaerobic filter • etc	• Human powered emptying and transport • Motorized emptying and transport • Simplified sewers • Small bore sewer • Conventional gravity sewer • Jerrycans, cart, tank etc	• Anaerobic baffled reactor • Anaerobic filter • Trickling filter • Waste Stabilization ponds • Activated sludge • Constructed wetland • Co-composting etc	• Application of urine • Application of dehydrated faeces • Compost • Irrigation • Aquaculture • Soak pit • Leach field • Land application • Surface disposal etc

Source: (Muanda 2014)

To simplify sanitation system planning, generic urban sanitation system 'types' have been considered to avoid reference to each and every technological option, especially in cases when application may not be viable. Thus, Table 3-4 gives a summary of some of the generic sanitation system types suggested by International Water Association (IWA).

Table 3-4: Sanitation System Typology

SYSTEM	General Description	Technical options		
		Toilet	Grey water	Stormwater
1A On-site dry	Dry latrines hygienisation and re-use of excreta in gardens.	Twin pits or , composting toilet	Infiltration, onsite reuse or discharge into drains	Onsite reuse, infiltration or discharge into drains
1B On site dry with (semi-) centralised treatment	Dry latrines, collection & treatment of faecal sludge at neighbourhood or city level before reuse in agriculture	Simple pit latrines	Infiltration or discharge into drains	Infiltration or discharge into drains
1C On site dry with urine diversion	HH latrine with urine separation. On-site reuse of urine in garden. Faeces dehydrated on-site. Possible reuse onsite or further downstream	Urine separating latrines, co-composting toilets, twin pits	Treatment and reuse at household level (eg constructed wetland)	Infiltration or discharge into drains
2A On site semi wet (pour-flush)	Latrine system at hh level with infiltration of liquid wastes, emptying of faecal sludge when full (additional hygienisation?) and reuse in garden or disposal	Twin pit pour flush or similar	Infiltration, onsite reuse or discharge into drains	Infiltration, onsite reuse or discharge into drains
2B On site wet with (semi) centralised treatment	As 2A with faecal sludge evacuation system, transport and treatment on neighbourhood or centralised level before reuse in agriculture	Twin pit pour flush or similar may have septic tank or ABR	Mixed with blackwater and treated on hh or neighbourhood level, infiltrated or reused in garden and agriculture	On-site use or infiltration as in 1A; discharge into drains, possible reuse in agriculture
3A Waterborne with (pre) treatment and (semi) centralized treatment	Toilet with on-site pre-treatment linked to small bore sewerage system.	Pour flush or flush toilet with septic tank/ vault or similar	Mixed with blackwater and transported for treatment	Discharge into drainage.
3B Waterborne with (semi) centralized treatment	Same as 3A however without pretreatment on hh level and uses simplified sewers	Pour flush or flush toilet	On-site use or infiltration as in 1A; or else discharge into drains for evacuation and discharge in surface water or reuse in agriculture	On-site use or infiltration as in 1A; or else discharge into drains for evacuation and discharge in surface water or reuse in agriculture
3C Waterborne with centralized treatment	Flush toilets and conventional combined sewers	Flush toilet	Mixed with black water in the sewer	Mixed with blackwater – possibility of storm-overflow and discharge to water bodies.

Source: (IWA 2006)

3.7 User Interface and Collection Components

Further discussion of sanitation systems is carried out with reference to the value chain components. Moreover, discussion of user interface and collection components are considered under the various sanitation system types i.e. dry onsite, semi wet and water borne system types summarised in the following Section.

3.7.1 Onsite Dry Sanitation Systems

These sanitation systems are appropriate where water is not required for anal cleansing and are adapted to water scarce environments. Pit latrines are the most common example in this category. The basic principle of all pit latrine types is that wastes such as excreta, anal cleaning materials and in some cases refuse are deposited in a hole dug in the ground. The liquid portion percolates into surrounding soil while organic material decomposes, producing carbon dioxide and methane which are either emitted to the atmosphere or dispersed into the surrounding soil. Consolidated residue can then be re-used as a soil conditioner if the level of treatment is considered to meet the WHO requirements (WHO 1992). Composting technology can also be applied in pit latrines where additional organic materials and possibly ash improves the quality of the end product (IWA 2006).

Variable examples of pit latrines exist and these include; simple or double pit latrine, urine diverting dry toilets (**UDDT**) which are specially designed to separate and store urine and faeces(IWA 2006; EAWAG-SANDEC 2008; Tilley et al. 2014). The urine is then used as fertilizer while faeces are treated in the pit prior to reuse, adapting the "sanitise and reuse" characteristic of **EcoSan**[11] systems. In alternate cases, residual material from pit latrines is collected and transported for further treatment. Transportation of the residual material is achieved using hand carts or trucks and further treatment at designated faecal sludge treatment plants is carried out. Overall, for such dry onsite systems grey water and storm water are either handled separately using drainage network or may be disposed of through infiltration based on local climate and ground conditions (IWA 2006; Tilley et al. 2014). Figure 3-3 and 3-4 show a double nit ventilated improved pit latrine and **UDDT**.

3.7.2 Semi -Wet Systems

In semi-wet sanitation systems, water is used for anal cleansing and these systems are often located on site. Ultimately the water is infiltrated into the ground while the semi-solid wastes are treated onsite in latrine pits, composting pits or similar provisions. Examples of such systems include; twin-pit pour-flush latrines which may additionally have a septic provision for pre-treatment (IWA 2006). Furthermore, biogas latrines where a biogas digester is connected to latrine and excreta is anaerobically digested in the digester producing digestate and biogas are additional examples in this category. The digestate generated can be used as fertilizer while biogas is used to generate energy mainly for cooking and lighting purposes (UNICEF 2014; IWA 2006). Further treatment of residual solid waste from the pit latrine can be carried out in similar manner as for dry sanitation systems while grey water can be mixed with black water. Figure 3-5 and 3-6 show the pour flash toilet and biogas latrine.

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[11] Ecological sanitation: implies separating waste streams, saving water and energy, nutrient recycling, cost efficiency, and the integration of technology to environmental, organizational and social conditions Jenssen et al. 2004.

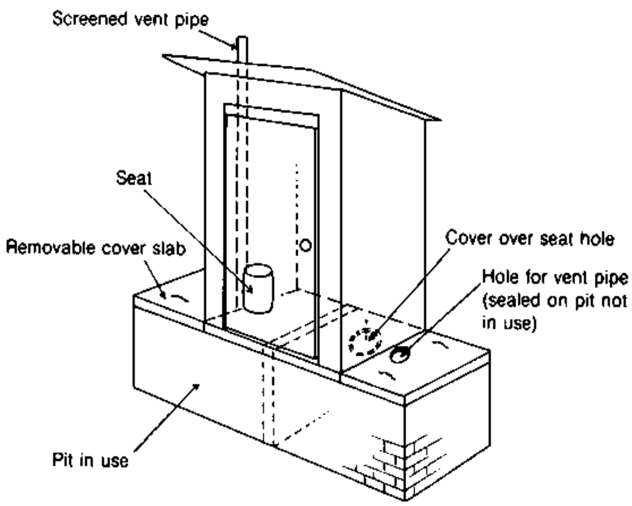

Figure 3-3; Double nit VIP latrine (UDDT)
Source; (Open University 2016)

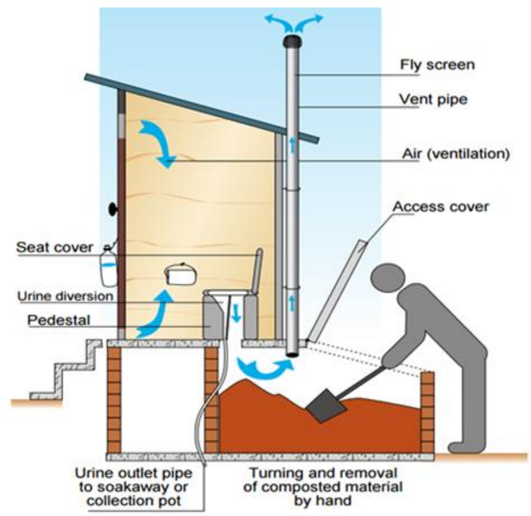

Figure 3-4: Urine diverting dry toilet

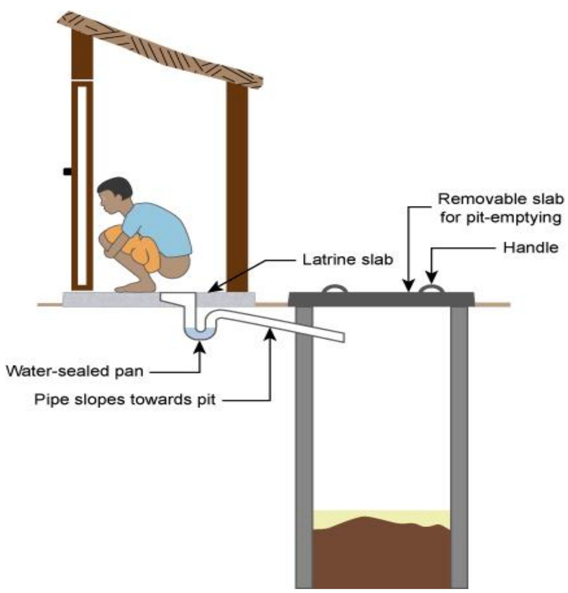

Figure 3-5: Pour flush pit Latrine
Source: (Open University 2016)

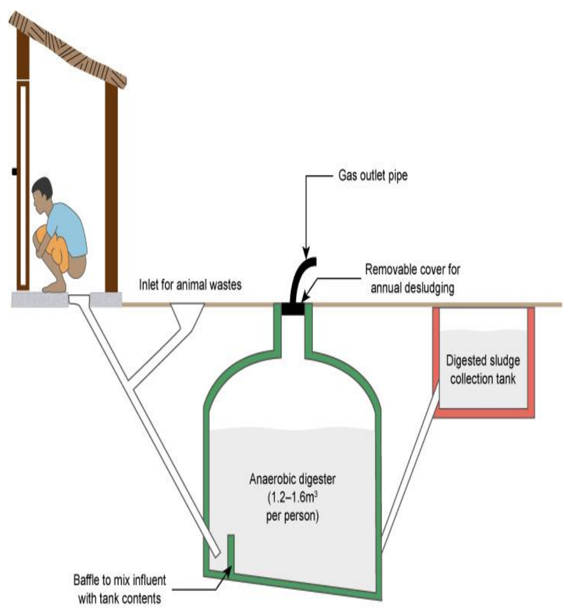

Figure 3-6: Biogas Latrine

3.7.3 Waterborne Sanitation Systems

The mode of operation for waterborne sanitation systems can be clustered into three groups. **Group 1** includes a pre-treatment of some kind which is carried out in a septic tank, anaerobic baffled reactor (**ABR**) or settling chamber. As such, only black and grey water is transported using small-bore sewers for decentralised or centralised treatment. **Group 2** still includes a pre-treatment stage however, grey water and storm water are kept separate while black water is transported for treatment using simplified sewers. Finally, **group 3** consists of the conventional system where black, grey and storm water is handled together in combined sewers or conventional separate sewers. The user interface of these sanitation system types are usually pour flush or flush toilets (IWA 2006; Tilley et al. 2014). Evidently, pretreatment is an important stage for waterborne systems thus, understanding the mode of operation of the common technologies used is imperative.

Septic tank; is commonly used in wastewater treatment for individual households in low-density residential areas, for institutions and related establishments. The mode of operation is partial treatment of wastewater in a sealed watertight concrete, fiberglass, or plastic tank. The wastewater is generated from toilets, kitchens and bathrooms and passes through into the septic tank (WHO 1992; Tilley et al. 2014). After a period of 1-3 days, the partially treated liquid leaves the tank and infiltrates to the ground and this is often through soak pits or tile drains in trenches. The settled material in the septic tanks forms a layer of sludge at the bottom of the tank which must be removed periodically. Despite being watertight, it is not recommended for septic tanks to be constructed in areas which have high groundwater tables or are flood prone. Moreover, since periodic desludging of the septic tanks is necessary, access to the septic tank should by planned for with allowance for vacuum trucks to access location (Tilley et al. 2014). Figure 3-7 shows a septic tank system.

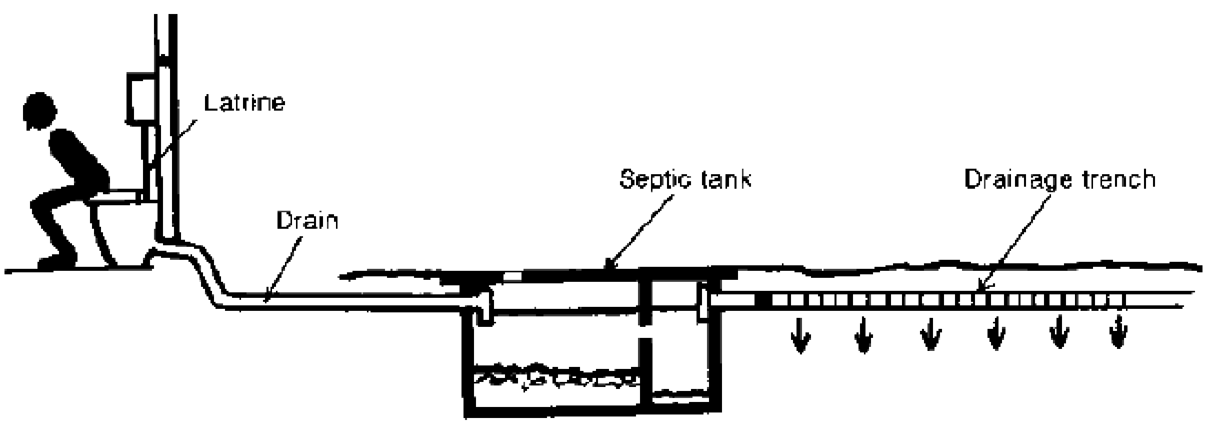

Figure 3-7: Schematic diagram of a Septic tank system
Source: (WHO 1992)

***Anaerobic Baffled Rectors (ABR*)**; which is also known as baffled septic tanks basically function as multi-chamber septic tanks. The increased contact time with the active biomass (sludge) as a result of forcing the wastewater through active sludge beneath chamber increases biodegradation and improves treatment**.** The **ABR** is suitable for all kinds of wastewater and is considered most appropriate for wastewaters with high percentage of non-settleable suspended solids and narrow chemical oxygen demand(COD) to biological oxygen demand(BOD) ratio (Gutterer et al. 2009; Tilley et al. 2014). The **ABR** technology is easily adaptable at various levels or climates and can be applied at the household level, in small neighborhoods or bigger catchment areas. Furthermore, **ABRs** can operate under variable climatic conditions although the system efficiency is lower in cold climate. The technology is most appropriate where relatively constant amounts of black and grey water are generated (Gutterer et al. 2009). Figure 3-8 shows a schematic diagram of the **ABR**.

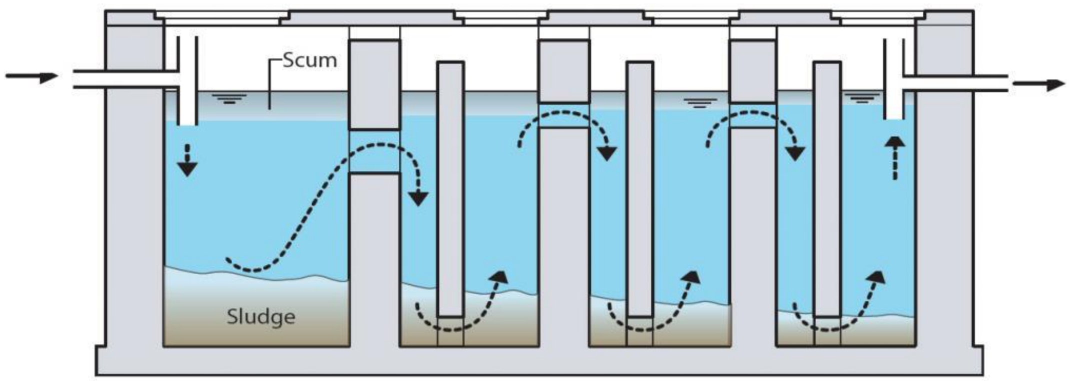

Figure 3-8; Schematic diagram of an Anaerobic Baffled Reactor
Source: (LET 2016)

Waste stabilisation ponds (WSP); are considered efficient for wastewater treatment and are especially appropriate for rural and peri-urban communities which often have large unused land at considerable distance from homes and public spaces. **WSP** are large manmade water bodies which can be used individually or linked in a series for improved treatment of wastewater. Three types of ponds normally exist and these include;
Anaerobic pond, where treatment of wastewater occurs in the absence of oxygen. ***Facultative pond,*** where treatment is a result of aeration at the top while treatment occurs anaerobically at the bottom part of the pond.
Aerobic or maturation pond is quite shallow and this allows for sun light penetration and aeration by wind mixing. Photosynthetic algae release oxygen, enhancing treatment of wastewater through the support of aerobic bacteria (EAWAG-SANDEC 2008; Tilley et al. 2014). Figure 3-9 shows the **WSP**.

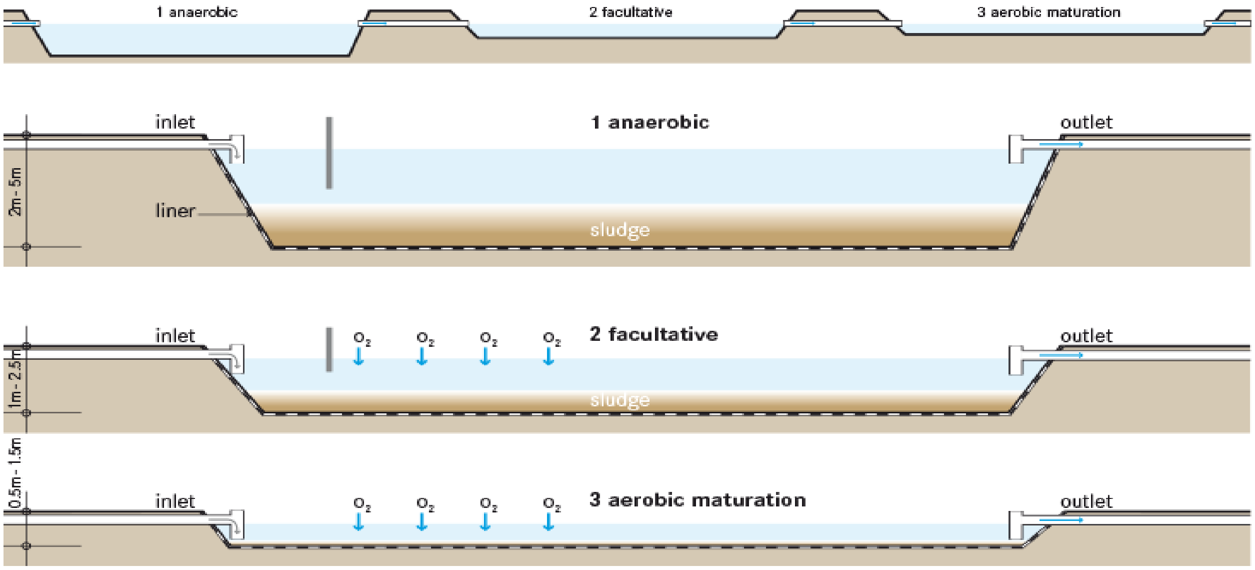

Figure 3-9; Schematic diagram of Waste Stabilisation Ponds
Source: (Tilley et al. 2014)

The discussion for dry onsite, semi wet and waterborne systems highlight the user interface and collection/storage components of the sanitation system value chain. Particularly, the pit latrine options discussed represent user interface as well as collection and storage/treatment components. While the septic tanks, **ABR** and **WSP** represent mainly collection/treatment component of the sanitation system value chain. In Sections 3.8 and 3.9, discussion of conveyance and treatment components is carried out.

3.8 Conveyance Components.

Commonly utilised conveyance technologies in urban settings of developing countries include; containers which are mostly plastic in nature in addition to hand powered and motorised emptying systems and sewer systems.

Plastic Containers; are often used when urine is separated from faeces although buckets for faecal matter may also be used. The plastic jerrycans/containers are used for storing and transporting urine to agricultural fields or to central storage facilities. Transportation is enhanced using bicycles, donkeys, carts or small trucks. Proper sealing of the jerrycans is necessary to avoid any health risks even though urine is sterile (Tilley et al. 2014; IWA 2006).

***Human powered emptying and transport*;** considers different ways people can manually empty and transport sludge or solid products from onsite sanitation facilities. In Uganda for example, the gulper unit is fitted on top of a pipe which is then inserted in the pit latrine. Faecal matter is then manually pumped out and stored in containers for transportation to locations for further treatment (WaterAid 2009).

The gulper is appropriate for extracting liquid and viscous sludge to a certain degree. Domestic refuse in the pit makes emptying much more difficult using the gulper. To avoid health related risks, worker operating the gulper should wear protective gear like gloves, boots, overalls and facemasks (Tilley et al. 2014). Figure 3-10 and 3-11 show the storage jerrycans and gulper system often used.

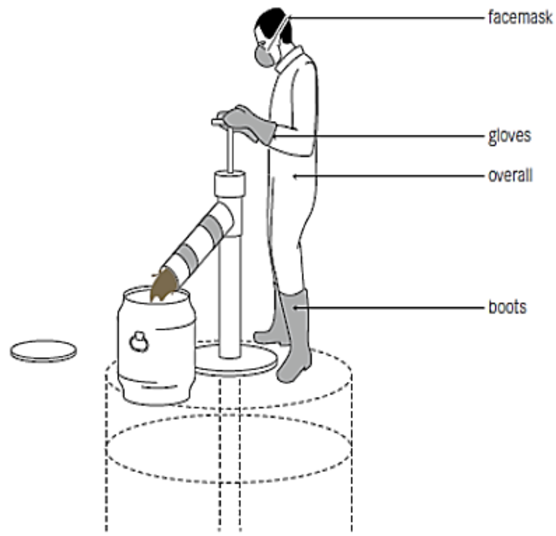

Figure 3-10; Plastic jerrycans for urine & feces **Figure 3-11; The gulper**
Source: (Tilley et al. 2014)

***Motorised Emptying and Transport*;** basically uses vehicles or trucks which are often equipped with a motorised pump and a storage tank for emptying and transporting faecal sludge and urine. Man power is mainly required for operating the pump and maneuvering the hose while lifting of the faecal sludge from the pits or septic tanks is accomplished by the motorised pump prior to storage and transportation to designated location. Important to note is that access for such trucks to locations where sludge or faecal matter is pumped out from is an enabling factor (Tilley et al. 2014).

***Sewer Systems*;** mainly consists of a connection of pipes laid at variable gradients and constructed to channel wastewater, grey water or storm water to treatment facilities. The sewers may be simplified, solid free or conventional.
Simplified sewers consist of smaller diameter pipes laid at shallower depth and flatter gradient.
Solids-free sewers consist of a network of much smaller-diameter pipes and transport pre-treated and solid-free wastewater.
Conventional gravity sewers include large networks of underground pipes conveying black water, grey water and storm water from individual households to a semi or centralised treatment facility using gravity (Tilley et al. 2014; Metcalf and Eddy 2004).

Worthy of mention is that vast investments are required for the implementation of the conventional sewerage systems, with annual per capita costs for connection to sewer systems estimated to range between 24-260US$ (Rosemarin 2008; Smith et al. 2014). Expenses are additionally incurred during operation and maintenance of the sewer systems which could range between 12-28US$ (Lüthi et al. 2011b; Smith et al. 2014).

3.9 Semi or Centralised Treatment Component

A wide range of technologies are applied for treatment of excreta and sullage, some of which have already been mentioned in Sections 3.7.2. Thus, this section focuses on conventional wastewater treatment and faecal treatment technologies.

3.9.1 Conventional Wastewater Treatment-Waterborne Systems

Usually the treatment of wastewater at conventional centralised treatment plants is carried out based on three key objectives and these include; reduction of the environmental impact on receiving bodies, meeting the treatment objectives, maximising treatment level and efficiency. Assessing the environmental impact is necessary to evaluate compliance of discharge from the treatment plants with receiving body standards. Treatment levels and efficiency are associated with removal of pollutants from wastewater so that effluent reaches required quality and the treatment objectives are achieved (Marcos von Sperling 2007; Metcalf and Eddy 2004).

Wastewater treatment in conventional plants is classified into four major levels namely; preliminary, primary, secondary and tertiary. Essentially only coarse solids are removed in the preliminary stage while settleable solids and part of the organic matter are removed during primary treatment. Secondary treatment aims at the removal of organic matter and mainly nitrogen and phosphorus nutrients using biological treatment methods. Tertiary treatment focuses on the removal of specific pollutants like toxic and non-biodegradable compounds (Metcalf and Eddy 2004; Marcos von Sperling 2007). Further discussion of wastewater treatment systems can be referred to in appendix 1.

3.9.2 Faecal Sludge Treatment.

Faecal sludge can be treated using physical or biological methods which consider various technologies/processes. The most commonly applied method is a combination of filtration and drying of faecal sludge. Filtration mechanism helps separate liquid and solids in the faecal matter and filter media such as gravel is used to trap solids on the surface of the filter bed. The liquid portion separated percolates through the filter bed and is collected in drains, or evaporates from the solids. Slow filtration occurs at slow rates between 0.1-0.4 m/h in the drying beds and this reduces operations and maintenance requirements. When planted drying beds are used, dewatering of faecal sludge in the drying beds occurs through evaporation or evapotranspiration (Strande et al. 2014). Figure 3-12 shows faecal sludge drying beds at Lubigi treatment plant in Uganda

Figure 3-12; Faecal sludge drying beds at Lubigi treatment plant, Uganda
Source: Author

3.10 Use or Disposal Component

This sanitation system value chain component consists of different technologies and methods that use or dispose of the byproducts from the treatment phase in ways that are often least harmful to the users or the environment (IWA 2006; Tilley et al. 2014). Examples within this component include filling and covering of pit latrines when ready for decommissioning. In the Arborloo latrine for instance, a tree is planted on top of the full pit while the superstructure or ring beam and slab are moved from pit to pit in an endless cycle. Generally, filling and covering pits is only an adequate mechanism when emptying is not possible and when there is available space to continuously re-dig and fill pits. In cases where separation of faeces and urine is practiced, application of urine as liquid fertilizer after storage over a period of 6 months can be carried out. On the other hand the dehydrated faeces can also be applied for agriculture after storage for a period of 12 to 18 months. The storage period of the dehydrated faeces allows for deactivation of pathogens although this may vary based on conditions. Other applications include use of treated wastewater effluent for irrigation or in aquaculture to mention but a few. While sludge can also be applied on land for landscaping or agriculture (IWA 2006).

3.11 Solid Waste Generation and Management.

Management of solid waste in urban areas is often the mandate of local governments. Solid waste is considered one of the most pernicious local pollutants and is generated from various sources which include; households, business establishments, institutions, industries and public area (World Bank 2012). Most developed countries have prioritised **MSW** management by adopting strict regulations, developing innovative measures for its use such as generation of energy from **MWS** while additionally ensuring adequate monitoring (World Bank 2012; Simelane and Mohee 2012).

In developing regions such as Africa, **MSW** management has not yet reached such a high level of prioritisation because direct and indirect factors heavily influence management. An appreciation of the key influencing factors would enhance management of **MSW**. Simelane and Mohee (2012) suggest that a range of factors influence **MSW** management in Africa and these factors include; natural environmental concerns, social norms and associated concerns, economic factors, historical influences, political contexts, local, regional and national legislation, institutional and educational factors, technological developments, human resource deployment and financial constraints (Simelane and Mohee 2012). Therefore, in planning for proper **MSW** management, consideration of all or some of the factors mentioned with respect to context would enable attainment of effective results. Moreover, as earlier highlighted, (Okot-Okumu 2012) points out that for major cities in East Africa and urban centres in Uganda, solid waste is composed of atleast 70% organic waste. Furthermore, the common method of solid waste management is landfilling although other methods such as composting and anaerobic digestion are also used as discussed.

3.11.1 Landfilling;

Dumping of waste in designated areas known as a landfill is still one of the most applied methods of waste disposal in Africa despite the high composition of organic waste in the total solid waste stream. Decomposition of the organic waste component in the landfills results in methane production which is a powerful greenhouse gas i.e. 28 times the global warming potential of carbon dioxide for 100 year time horizon (GGP 2014; Trottier 2014). In addition, the leachate generated from the aerobic and anaerobic processes taking place in a landfill can lead to contamination of groundwater by heavy metals and related emissions if not controlled (Palczynski 2002; Ludwig et al. 2003). In developed nations landfilling of waste is declining due to advanced regulations encouraging waste reduction and recycling (Scarlat et al. 2015).

Regions like Europe have made strides in ensuring reduction of organic/biodegradable waste dumped in landfills through legal interventions such as implementing the Landfill directive (1999/31/EC). This directive obliges member states to reduce the amount of biodegradable municipal waste landfilled to 35% of 1995 levels by 2016 (EU 1999). To enhance **MSW** management, Africa could learn from working positive examples in developed countries. As such, sorting of waste streams and application of other additional measures for management of organic waste could be some of the measures considered.

3.11.2 Composting

Composting is a process by which organic materials undergo biological biodegradation to a stable end product. Both anaerobic and aerobic conditions enable the composting of organic waste which results in a pathogen free compost product used as soil amendment for agriculture, landscaping, and horticultural applications (David 2013; Taiwo 2011). Anaerobic composting is basically a low-temperature process which may not completely destroy the pathogens in organic waste. In addition, strong odors are generated hence, anaerobic composting is not recommended for urban agriculture.

Aerobic composting on the other hand is characterized by high temperature generation due to the development of microbes. These microbes generate higher temperatures in the compost pile which in turn destroy pathogens in the organic waste. Compost generated from either or a combination of anaerobic and aerobic processes helps in erosion control and prevention of further loss of topsoil in areas where it is disturbed or applied (David 2013). The benefits from composting of organic waste justify the variable application at different levels i.e. household, community and city level (Kinobe 2011; Taiwo 2011; David 2013). In certain cases composting of organic waste has been integrated into landfill cover systems and has been successfully used as part of methane oxidation cover systems, which passively treat landfill gas emissions (David 2013).

In Uganda, about 17 composing plants have also been incorporated as part of landfill infrastructure in various major towns. This national program spear headed by the national environment management authority (NEMA) is one of the measures in place to reduce organic waste streams dumped in the landfills. Hence, these composting projects are registered under the auspices of clean development mechanism projects in the country (CDM 2009). As such, organic waste collected from various locations within the towns/municipalities i.e. markets and waste skips located near residential areas is sorted at the landfill prior to composting. The generated compost is then sold to interested customers who use it mainly in agriculture and landscaping. Figure 3-13 shows a composting section at Mukono Municipality landfill.

Figure 3-13: Composting section within Mukono Town Landfill.
Source: Author

3.11.3 Incineration

The role of waste incineration differs from country to country worldwide. Often the case, large proportions of waste i.e. up to 100% is incinerated, especially in industrialised countries in Europe as well as in Japan, USA and Canada to mention but a few (Wiechmann et al. 2013; Reddy 2016; MoEJ 2012). While in most of the developing countries, landfilling is still the most common waste management practice. Incineration of waste is often practiced at small scale with common applications noted in medical facilities, where incineration of medical waste is carried out. Nevertheless, gradual increase in application of incineration for municipal solid waste can be traced in developing countries. In the African region, South Africa is one of the main countries operating incinerators for waste management (Luckos and Hoed 2011).

Incinerating solid waste basically involves combustion of the waste in excess supply of oxygen. Waste incineration fulfills two purposes which include; reduction of the amount of waste for sanitary landfilling; and utilisation of waste for energy production (heat and power). As such, waste incineration plants are generally introduced in areas where the siting of sanitary landfills is in conflict with other interests such as city development, agriculture, and tourism. Solid waste incineration on a large scale is a highly complex technology, which involves large investments and high operating costs. This implies that income from the sale of energy makes an important and necessary contribution to the total incineration plant economy(World Bank 1999; Wiechmann et al. 2013; Rand et al. 2000).

Various types of incineration technologies are currently available although the most widely used is mass burning incineration with a movable grate or in certain instances rotary kilns are used. Moreover, when incineration of sewage sludge is additionally considered, then technologies such as fluidised bed furnaces, multiple-hearth furnaces, as well as cycloid furnaces can be used. Incineration of waste is still considered among the most expensive solid waste management options. Moreover, the process additionally requires highly skilled personnel and careful maintenance for efficient operation. As such, incineration tends to be a good choice only when other, simpler, and less expensive choices are not available or have been exploited (Rand et al. 2000; Wiechmann et al. 2013; FEA 2014; Luckos and Hoed 2011).

3.11.4 Anaerobic Digestion

During anaerobic digestion, organic matter is decomposed in the absence of oxygen. This microbiological process is common to many natural environments such as swamps or stomachs of ruminants (Al Seadi et al. 2008; Vögeli et al. 2014). Anaerobic digestion (AD) has been practiced for decades in developing countries with application dating back to 1859 in India where the technology was used to sewage treatment. In their review of **AD** application, Mata-Alvarez et al. (2014) highlighted that the oldest and most widely spread application of **AD** was the treatment of sewage sludge. **AD** is applied for stabilisation of the organic sludge produced from **WWTP**s.

The interest in **AD** application for treating other organic solids such as food processing waste, energy crops and other organic waste has grown rapidly. Such trends have been boosted by recognition that valuable products like biogas and organic fertilizer can be obtained from **AD** of organic material. Increasing energy demands, new and strict regulations on organic waste disposal and the need for alternative energy sources to fossil fuels have further boosted application of **AD** (Esposito et al. 2012). Thus, **AD** technology for the management of organic waste streams, including sewage sludge has been considered attractive due to the potential benefits which include; volume reduction of material prior to disposal, prevention of pollution of soils, air and groundwater, production of biogas used as an alternative energy source and digestate utilized as organic fertilizer (Al Seadi et al. 2008; Khalid et al. 2011).

AD *is a biochemical process during which complex organic matter is decomposed in the absence of oxygen by various types of anaerobic microorganisms* (Al Seadi et al. 2008). The byproducts of the **AD** process are biogas composed mainly of methane, carbondioxide and digestate which is the decomposed substrate from the production of biogas. **AD** process is common to various natural environments such as the marine water sediments, the stomach of ruminants, in peat bogs etc. The process consists of four major steps which include; hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Hydrolysis; is theoretically the first step of **AD** where complex organic matter referred to as polymers are decomposed into smaller units (mono- and oligomers). Polymers such as carbohydrates, lipids, nucleic acids and proteins are converted into glucose, glycerol, purines and pyridines by hydrolytic microorganisms(Al Seadi et al. 2008).

Acidogenesis; products from the hydrolysis stage are converted by acidogenic or fermentative bacteria into methanogenic substrates. Thus, simple sugars, amino acids and fatty acids are degraded into acetate, carbondioxide, hydrogen and into volatile fatty acids (VFA) and alcohols (Al Seadi et al. 2008).

Acetogenesis; in this stage products from acidogenesis i.e. VFA and alcohols, which cannot be directly converted to methane by methanogenic bacteria are converted into methanogenic substrates (hydrogen, carbondioxide and acetate). Overall, homoacetogenic microorganisms (e.g., *Acetobacterium woodii* , *Ruminicoccus hydrogenotrophicus*) constantly reduce exergonically hydrogen and carbondioxide to acetic acid (Deublein and Steinhauser 2011). Equation 1 gives a summary of the reaction

$$\mathbf{2CO_2 + 4H_2 \xrightarrow{\text{Acetogenic microorganisms}} CH_3COOH + 2H_2O} \text{ ....Equation 3-1}$$

The production of hydrogen at this stage not only increases the hydrogen partial pressure but also inhibits the metabolism of the acetogenic bacteria. During methanogenesis, hydrogen is converted into methane. Acetogenesis and methanogenesis usually run parallel as symbiosis of two groups of organisms(Al Seadi et al. 2008).

Methanogenesis; is a critical step in the entire anaerobic digestion process, as it is the slowest biochemical reaction of the process. This stage mainly includes the production of methane and carbondioxide from intermediate products and is carried out by methanogenic bacteria. About 70% of the formed methane originates from acetate, while the remaining 30% is produced from conversion of hydrogen (H) and carbon dioxide (CO_2). The methanogenesis stage is severely influenced by operation conditions. As such, composition of feedstock, feeding rate, temperature, and pH are examples of factors influencing the methanogenesis process. Equations 3-2 and 3-3 give an overview of the methanogenesis reaction while Figure 3-14 shows the key steps in the anaerobic digestion process (Al Seadi et al. 2008; Deublein and Steinhauser 2011).

$$CH_3COOH \xrightarrow{\text{Methanogenic bacteria}} CH_4 + CO_2 \quad \text{.............................Equation 3-2}$$

$$4H_2 + CO_2 \xrightarrow{\text{Methanogenic bacteria}} CH_4 + 2H_2O \quad \text{............................. Equation 3-3}$$

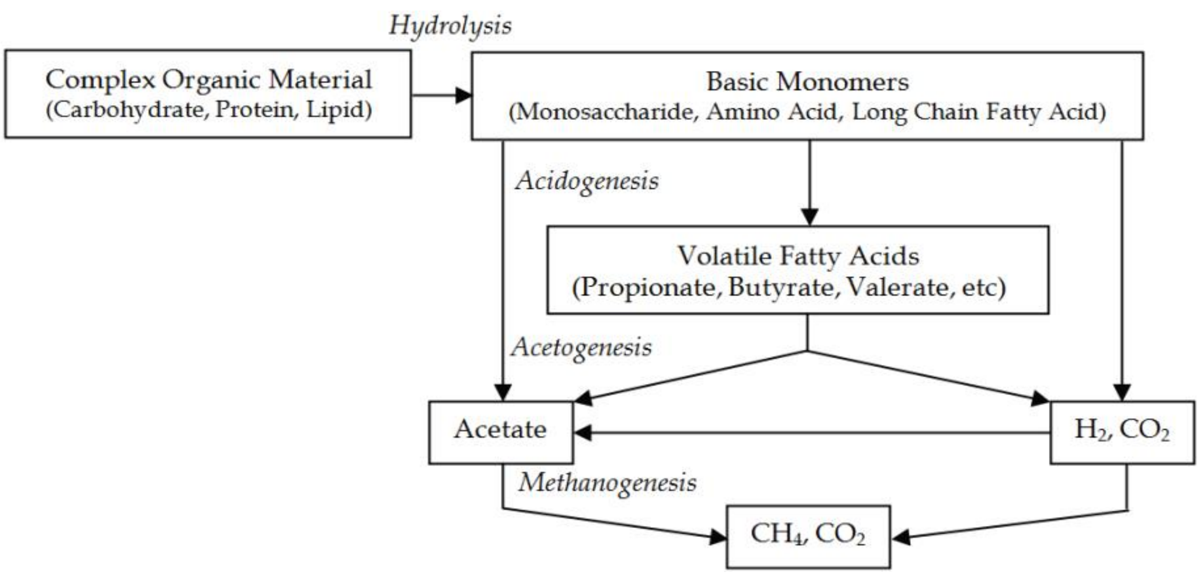

Figure 3-14: Steps of Anaerobic Digestion Process
Source: (Samer 2015)

Methanogenesis is a critical step of the entire anaerobic digestion process and is also the slowest biochemical reaction of **AD**. Methanogenesis is strongly influenced by operation conditions some of which include; composition of feedstock, feeding rate, temperature, nutrient content, pH, carbon/nitrogen (C/N) and carbon/phosphorus (C/P) ratio among others. As such, overloading of the digester, temperature changes or entry of large amounts of oxygen can result in termination of methane production (Al Seadi et al. 2008).

Despite the application of **AD** for management of a wide range of organic materials, experience has shown that **AD** of single organic waste substrates has various draw backs which are mainly linked to substrate properties. Hence, **AD** co-digestion of two or more substrates has been found to solve some drawbacks associated with mono-digestion of substrates. Literature suggests that **AD** co-digestion boosts dilution of toxic compounds, increases load of biodegradable organic matter, improves balance of nutrients, synergistic effect of microorganisms and results in better biogas yield (Khalid et al. 2011; Al Seadi et al. 2008).

This application of **AD** is quite popular in developed countries where organic household waste mixed with other waste streams is degraded in centralised high-technology plants, generating biogas and digestate (Vögeli et al. 2014). Developing countries such as Uganda are gradually catching up with the trend of co-digestion of organic waste streams on a large scale. India seems to be the most prominent developing nation practicing **AD** with regards to processing of organic waste although the assessment is based on available literature on the topic (Vögeli et al. 2014; Khalid et al. 2011). In the African region, the most prominent application of **AD** is still in treatment of wastewater, human excreta and animal waste especially cow dung (Heegde, and Sonder 2007).

The integrated sanitation system approach suggested in this research considers combined management of organic waste streams using a combination of anaerobic digestion and other processes/technologies such as composting, incineration and solar drying among others. Given that the approach is conisdered applicable in urban areas in Uganda, appreciation of specific entities for which the integrated sanitation systems would be applicable is important. As such, the following section discusses the potential entry point for the integrated sanitation system approach in the urban areas within Uganda.

3.12 Identification of Entry Points for Integrated Sanitation Systems in Uganda

The entry points through which integrated sanitation systems proposed in this research could be possibly considered were identified by referring to areas where opportunities for making an impact were cited. These areas were further identified by considering areas where the demand for improved sanitation services exist. Moreover, areas where certain contextual factors provide an opportunity for change are also considered. For instance, areas where incomplete management of organic waste is anticipated were taken into account. Meanwhile, areas where availability of organic waste streams is anticipated as well as those areas where additional requirement for energy from sources such as biogas exits were also considered. To further inform the identification of entry point for integrated sanitation systems approach, urban areas were considered as a patch-work of different domains and physical environments (Lüthi et al. 2011b). As such, each of the patches within the urban areas presents their own challenges and opportunities as discussed for the entry points.

3.12.1 Non-Residential Buildings or Settlements

Usually these buildings or settlements include schools, health clinics, hospitals, markets, tourism facilities and office buildings among others. They contribute to affordable services for a city's or town`s residents and may be frequented by thousands of users on a daily basis. Due to the nature of these settlements or buildings, they offer a special opportunity for innovative sanitation technology since it can be possible to implement systems not available at individual residence(Lüthi et al. 2011b).

Uganda has atleast 200 institutions of higher learning and these include public and private universities, teaching, technical and agricultural colleges and various training institutions among others. Moreover, there are numerous private and government operated primary and secondary schools spread throughout the country. In the schools and institution of higher learning various sanitation systems/facilities are used and these may include; pit latrines, pour/flash toilet connected to stabilisation ponds or septic tanks, own treatment systems or **WWTP**, bio-latrines/ toilets to mention but a few(refer to Chapter 3 for discussion of sanitation systems). Irrespective of the sanitation systems already in place at the schools or institutions, there may be need for further management of faecal or sewages sludge. According to a report by the Water Research Commission, Uganda has only 16 designated centralised **WWTP** spread throughout the country, where faecal sludge is additionally managed at a fee (WRC 2015; MoWE 2016). Despite the noted efforts to avail facilities for management of sewage and faecal sludge, the limited number of treatment plants in a country currently consisting of **111** districts exposes a sanitation gap in need of additional management of sewage/faecal sludge.

Furthermore, most of the institutions of higher learning and schools provide food for the students, teaching and non-teaching staff, irrespective of if they offer boarding (residing in premises) or day services. As such, energy sources are required for cooking purposes. The predominant source of energy for cooking in most of the institutions in Uganda includes firewood and charcoal. In 2013 alone, institutions used at least 1.8million tones of firewood and this highlighted the high demand for biomass as a cooking fuel (MEMD 2013). The fact that meals are availed to students, teaching and non-teaching staff at the various institutions of learning and schools implies that kitchen or organic waste is also generated. Therefore, with the available organic waste streams in the form of kitchen waste, sewage or faecal matter and high demand for cooking energy, there exists an opportunity for implementation of integrated sanitation systems in schools and institutions of higher learning.

Already some schools have put in place biogas latrines/toilets hence, in addition to ensuring sanitation management at the schools, biogas is generated and used for cooking purposes, reducing costs that would be incurred in purchasing firewood to meet cooking demands. Implementation of bio-latrines in schools within the country has been promoted by organisations such as **UNICEF**, **GIZ** as well as government interventions by Ministry of Energy and Mineral Development (**MEMD**) (UNICEF 2014).

In collaboration with various entities, **MEMD** has been involved in the installation of 10 bio-latrine demonstration units in schools and communities in different parts of the country (IWMI 2012; MEMD 2015). On an individual basis, few schools and institutions have installed own bio-latrines and biogas digester units.

With reference to hospitals and health centers, there is often an urgent requirement for all round energy supply to enable proper running of the facilities and yet, there have been reported cases of power blackouts in hospitals/health centers (The Observer 2016; Ssekweyama 2016). In certain cases solar generated energy is used at the health facilities rather than electricity from the national grid. Nevertheless for most hospitals, the main energy source is from the national grid and diesel run backup power systems are often relied on during power blackouts. Despite relying on diesel run power backups, the availability of fuel to run generators may not be guaranteed and this hampers operations at the facilities, sometimes leading to avoidable deaths.

Most of the hospitals also have decentralised sanitation systems in place while very few of them are connected to main sewer systems within towns. Depending on the location of the hospitals and the sanitation systems in place, further management of sewage or faecal sludge may be required. Moreover, most hospitals also have canteens where food stuff is cooked and sold implying that additional organic waste can be obtained. Therefore, similar to the schools and institutions of higher learning, hospitals or health centers also offer opportunities for possible implementation of integrated sanitation systems. The mere fact that institutions, schools and especially private hospitals are often managed by administrators or boards implies that the decision to implement integrated sanitation system will most often rest on the respective entities. As such, inconveniences and delays associated with bureaucratic tendencies can be reduced and this could be a driving factor for integrated sanitation system implementation. The integrated sanitation system offers solutions for sanitation management in addition to energy and nutrient recovery for the mentioned entities.

3.12.2 Planned Urban Development Areas

Planned urban areas are settlements which often have formal title deeds or simplified “right-to-use” titles and are zoned for specific uses. By the mere fact that these areas are planned implies that development is strongly influenced by politicians, government agencies. In most cases, commercial and private interests influence the planning process in these settlements. The residents of such areas may range from low to high income groups depending on designated land use i.e. housing projects, real estate developments. Such planned areas offer a great potential for implementing innovative sanitation solutions that contribute towards sustainable urban development (Lüthi et al. 2011b). Often the case, these developments are initiated on “green fields” hence, all necessary infrastructures has to be initially installed or developed, providing an opportunity to start from a clean slate. Intrinsically, a level of flexibility and possibility to install sanitation system innovations is quite high.

Development of housing estates in Uganda has thrived over the last decade due increasing population in cities and towns within the country. The current housing deficit at least 200,000 units would be required in urban areas annually (CR 2017, 2017; Nasanga 2016; CR 2017). With an annual urbanisation rate estimated at 5.4%, more housing units will be required in centers, towns and peri-urban areas of Uganda. To fulfill the housing shortage in Uganda, private real estate developers such as Akright, Jomayi Estates, HL Investments Ltd, Tirupati Ltd, Pearl Estates, Hosanna limited were established over the last decade. These private estate developers have stepped in to provide for the housing demand previously catered for by only National Housing and Construction Company Limited (NHCCL), the government house construction arm (Taremwa 2013; Giddings 2009).

The fact that these estates can be planned from the initial stages implies that provisions for source separation of waste allowing for resource recovery from organic waste streams can be practiced. Moreover, wastewater re-use incorporation of urban agriculture and biogas production can be explored in the estates. Given that private estate developers are the majority of the players in proving housing, a sense of flexibility in implementation of innovative sanitation systems exists. The desire to be a competitive estate developer can also be an additional driving factor for consideration of integrated sanitation systems in such establishments.

3.12.3 Peri-urban Areas

Peri-urban areas are considered to be midway or between the suburbs and countryside (Weeks 2010). Given that these are interface areas where urban and rural areas meet, great pressures on the natural resource base, on poor people's livelihood strategies in addition to access to land and on public amenities exist. These areas may be characterised by various factors such as; strong urban influences, easy access to markets, services and other inputs, ready supplies of labor. Moreover, these areas could also be characterised by relative shortages of land and risks from pollution and urban growth. In cases of space availability and close proximity to agricultural areas, then opportunities for decentralised technologies and reuse of treated effluents and sludge are available in peri-urban areas. Also, since these areas grow rapidly into formalised urban areas, they offer the potential to explore practical innovations in sanitation, which could then be replicated(Lüthi et al. 2011b; Peal et al. 2010). Burgeoning centers neighboring the main city and towns in Uganda are some of the examples of peri urban areas which could benefit from the integrated sanitation systems.

During the last two decades, Kampala city for example has expanded rapidly in all directions and incorporated former satellite towns such as Mukono, Entebbe, Mpigi and Bombo and surrounding rural areas. This rapid growth has extended the administrative city boundary, creating an urban surface covering of more than 800 km^2 , which is referred to as Kampala greater metropolitan (Vermeiren et al. 2012). Areas which were considered almost rural 20 years ago have quickly become peri-urban with lots of settlement, intuitional development and thriving businesses as shown in Figure 3-15.

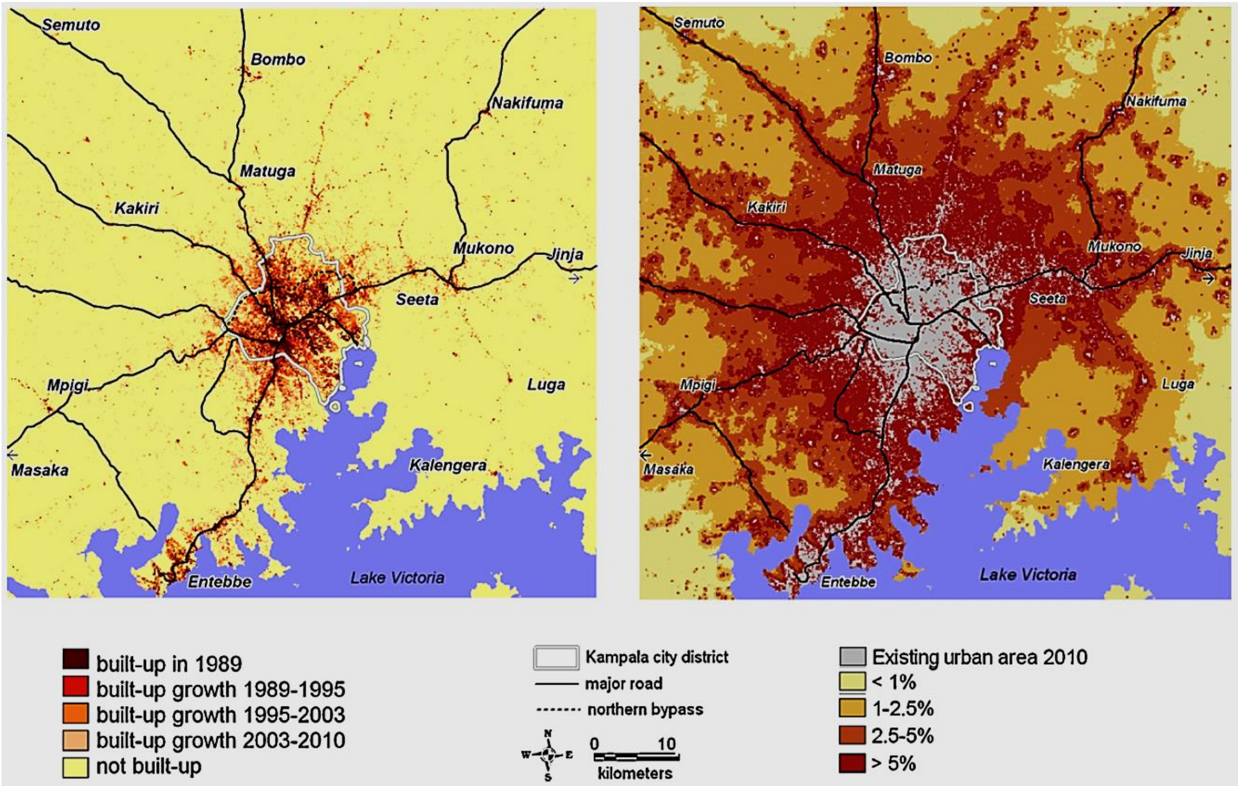

Figure 3-15: Observed urban expansion between 1989 and 2010 land in the Kampala metropolitan area. (b) Assessed probabilities for new built-up land in the Kampala metropolitan area
Source: (Vermeiren et al. 2012)

Usually, urbanisation of peri-urban areas is not consistent with infrastructural development thus, sanitation challenges may be prevalent, especially in the urban poor areas (Maseland and Kayani 2010; MoWE 2016). Depending on the various sanitation systems used in residential, institutional and business entities, faecal, sewage sludge and waste management services are often required. Extension of the city or town boundaries due to the rapid growth has led to establishment of administrative divisions and town councils which incorporate some of the peri- urban areas. The presence of such administrative arms in most towns and municipalities within the country creates opportunities for implementation of integrated sanitation systems in the adjacent growing centers. Moreover, the presence of "champions" to propose and support such implementations in peri-urban areas would be a crucial aspect. As such, involvement of local authorities within town councils or municipality divisions as champions for integrated sanitation systems would probably boost implementation.

3.12.4 Inner-city, Middle and High Income Settlements

These settlements are characterised by modern apartments in multi-storey and high-rise buildings. Here, residential buildings are often complemented by small-scale businesses, shops, restaurants, hotels and office buildings.

Also, such areas are characterised by high population density and water consumption. In most cases upgrading or retrofitting existing systems in such areas maybe an uphill task further influenced by occupants habits. Nevertheless, these settlements also offer opportunities for integrated sanitation system implementation since installation of completely new systems may not be necessary. Replacement or installation of additional functional groups can then be achieved (Lüthi et al. 2011b; Parkinson et al. 2014). As already cited in previous the Chapter, an example of integrated sanitation system is in the final stages of completion and would be operated by National Water and Sewage Corporation Uganda (**NWSC**). The centralised **WWTP,** which is expected to treat 46 million liters of wastewater from various parts of Kampala inner city will additionally manage sewage sludge and organic waste in the digester. The biogas produced will then be used for generating 650kW of electricity used at the plant while a portion of the biogas will be sold to interested customers (Otage 2016).

Plans are also underway to pilot **NAMA**[12] integrated waste management and biogas project in three municipalities of Jinja, Mbarara and Mbale. Treatment of wastewater and organic waste streams from the municipalities is envisioned in these plants, generating biogas in addition to managing sanitation. **NWSC** is expected to manage these projects once they are completed with the possibility of up scaling to other towns within the country (GEF 2015)**.** The mere fact that such initiatives are in the planning phase and up scaling is envisioned indicates that opportunities exist for implementation of integrated sanitation systems in major towns within the county.

Uganda currently has a total of 274 urban centres with a population of 8.3 million people and most of these centres are not covered by **NWSC** sewerage services. **NWSC** plans to achieve 30% national sewerage coverage by 2018. Moreover, faecal sludge management in Uganda is also still poorly developed with less than 10% of the toilet facilities in the towns being emptied (MoWE 2016; NWSC 2015). The limited availability of national sanitation services for faecal and sewage sludge management implies that there is still a wide service gap to be filled. The integrated sanitation systems approach proposed in this research could be one of the solutions filling the sanitation service gap identified in the urban centres. This approach could make sanitation service provision attractive since resource recovery is anticipated. The various jobs created along the system value chain are incentives for considering integrated sanitation systems for such areas.

Already **NWSC** and **Ministry of Water and Environment(MWE)** are in collaboration with the private sector to provide certain services within the faecal sludge management value chain and water provision (MoWE 2016; Schoebitz et al. 2016). Therefore, collaborations between the same government entities and private sector in implementation of integrated sanitation systems at various levels of the system chain would not be a new phenomenon.

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[12] National Appropriate Mitigation Actions NAMA; are any action that reduces emissions in developing countries and is prepared under the umbrella of a national governmental initiative

On the contrary, with the experiences obtained from pilot implementation of integrated sanitation plants by **NWSC**, the private sector interested in similar implementations could "leap frog" certain challenges. Thus, integrated sanitation system consisting of combinations of technologies/processes such as anaerobic digestion, composting, incineration processes and solar drying among others could be considered. Therefore, from the review, it would be prudent to say that there is great potential for implementation of the integrated sanitation system approach suggested in this research for urban and peri-urban areas of Uganda. The requirement for sanitation services in rapidly growing urban areas, coupled with the energy demand and potential availability of organic waste streams among others, are positive driving factors for implementation of integrated sanitation systems.

In conclusion, this Chapter focuses the spotlight on the potential impacts of poor sanitation and goes further to appreciate the main challenges to sanitation provision in the Sub-Saharan Region. Thereafter, a review of key sanitation systems applied in the region is carried out before the Chapter concludes with the identification entry points for the integrated sanitation system approach proposed in this research. With reference to the literature review detailed in Chapter 2 of this dissertation and the discussion to understand pertinent issues to sanitation in Uganda and Sub-Saharan Africa as a whole, a conceptual framework of this research is discussed in Chapter 4.

4 Conceptual Framework of the Research

Chapter 4 *presents a conceptual framework of the research. The framework gives an overiew of how the research is carried out.*

4.1 Research Framework

The research is carried out in four phases, which include the initiation phase, feasibility assessment, sustainability assessment and the development of a planning framework for the integrated sanitation system approach. The initiation phase basically considers the existence of demand or interest for improvement of sanitation management as an ignition of the whole process. Moreover, preliminary stakeholder identification is also carried out at this phase. In addition, the assessment of the local context, taking into consideration the existing physical and socio-economic environment of the designated area is carried out to obtain a good understanding of the area. The information collected at the initiation phase informs the preliminary design of integrated sanitation system alternatives, which are further refined based on expert/researcher opinion in collaboration with relevant stakeholder input. Once the integrated sanitation system alternatives are designed, holistic feasibility assessments of the system alternatives are carried out. The holistic feasibility assessment phase considers four main aspects i.e. the economic, environmental, socio-cultural and technical aspects of the sanitation system alternatives.

The health aspect is not directly included since it is considered that sanitation system alternatives should ideally comply with health and hygiene standards. Thus, it was assumed that the inclusion of the health aspect would not really discriminate between the sanitation system alternatives designed as also suggested by (Loetscher 1999). Nevertheless, indirect inclusion of the health aspects could be preliminarily traced under the environmental impacts, especially with regards to the impacts due to the sanitation system operations. In addition, the health aspect could also be linked to the potential benefits associated with reducing the burden of health or avoided health costs due to improved sanitation.

4.2 Aspects Considered

Given that the integrated sanitation system approach considers as holistic approach, which basically incorporates the sustainability concept, the four main aspects considered for feasibility assessment are also later considered as pillars of sustainability, enabling sustainability assessment of the sanitation alternatives. A discussion of the aspects which include economic, environmental, technical and socio-cultural follows.

4.2.1 Technical Aspect

The focus of the technical aspect with reference to sanitation systems relates to the functionality of the system (Andersson et al. 2016a). Given that a sanitation system often consists of a combination of variable technologies/processes, assessing the system to validate if its objectives are fulfilled is imperative.

In examination of the functionality of a sanitation system, key parameters often considered are robustness, flexibility, adaptability and durability among others. Robustness is an important parameter for determining long-term functionality of a sanitation system. Irrespective of variations in load, which may especially be significant in decentralised systems, the sanitation system`s functionality should remain consistent. Hence, other variations such as power cuts, flooding or water shortages should not affect the sanitation system functionality. The flexibility of the sanitation system to adapt to changing resource demands over time is also an important technical factor (Andersson et al. 2016a; Vleuten-Balkema 2003). Another parameter relevant for technical feasibility assessment of sanitation systems is the system`s durability or lifetime. Sanitation system durability also reflects a lot on the cost implications since any required repairs and maintenance can only be achieved at a cost.

Moreover, the level of skill required in operation and maintenance of the sanitation systems cannot be ignored since there is often a direct correlation between the level of skill and labor costs. With reference to this research, three main parameters also referred to as criteria were considered and these included robustness, complexity and flexibility of the integrated sanitation system alternatives. Given that most sanitation systems may have a life time of at least 20 years, durability as a criterion was not considered since no discrimination between alternatives was anticipated with reference to this criterion. Furthermore, the integrated sanitation system alternatives consider a combination of processes/ technologies thus, a level of complexity was expected. Besides, combined management of the various organic waste streams would require for a system to be robust and flexible. Therefore, in this research, the technical feasibility assessment of integrated sanitation system alternatives considers three criteria i.e. robustness, flexibility and complexity of sanitation systems.

4.2.2 Environmental Aspect

Accompanied by the additional objectives of environmental protection and resource recovery, limitation of sanitation system designs to cater for only public health requirements is no longer the norm (Andersson et al. 2016a; Andersson et al. 2016b; Lüthi et al. 2009). As such, environmental feasibility assessment of sanitation systems often considers evaluation of resource utilisation by the system, impact on environment and resource recovery (Vleuten-Balkema 2003; Van Buuren 2010; Gabi 2011). Depending of the sanitation systems in use, various resources may be required. These resources may include energy in the form of heat and or electricity and other additives to boost the various treatment processes. Impacts to the environment from sanitation systems often result from emissions to the soil, water or air in the form of effluents, untreated sludge, hazardous gases and heavy metals to mention but a few. The growing realisation that societies can no longer afford to misuse water, nutrients, organic matter and energy contained in sanitation and other wastewater or organic waste streams has further promoted resource recovery from sanitation. As such, resource recovery from sanitation is often emphasised and considered an indication of a sustainable sanitation system (Schertenleib 2002; EAWAG-SANDEC 2000; Andersson et al. 2016a).

Given that the integrated sanitation system approach considers combined management of various organic waste streams, improper management of these waste streams could result in discharge of emissions to the environment. Moreover, resources in the form of energy and possibly additional additives may be required in the treatment or management processes. Meanwhile, depending of the processes or technologies applied resources in the form of biogas which can be used for energy generation and nutrients used as organic fertilizer could be recovered. It is against this background that resource use, impact assessment and resource recovery were considered as criteria for assessment of integrated sanitation system alternatives within the environmental aspect.

4.2.3 Economic Aspect

The core objective of an economic assessment is to determine if the proposed business, project or technology is economically viable (Overton 2007). Within this scope, assessment of the economic impacts of a project is carried out and this can be reflected positively through computing business sales, value added for customers, wealth increase and job creation or employment opportunities among others. Depending on the project assessed, negative economic impacts may result. For example, poor sanitation could affect household incomes and livelihood as already mentioned in Chapter 3. It is no secret that economic and or financial viability of projects are key components in the respective planning and implementation processes.

Often the case, discussions regarding business economics and socio-economics are mixed up. With reference to sanitation for example, socio-economics attempts to link impacts of poor sanitation to economic losses. Meanwhile, at the same time a business case for a sanitation system or intervention maybe argued out with reference to the economic returns associated with reducing the burden of health, environmental issues and even citizens' lost time and productivity. These returns when translated into cash flows, make the business case for the various sanitation system alternatives and this influences investment (TBC 2016; WSP 2008; McIntyre et al. 2014). In this research, a similar stance was considered in assessing the economic feasibility of the integrated sanitation system alternatives as such, life cycle costs and benefits from the system are considered defining criteria for the economic aspect.

4.2.4 Socio-Cultural Aspect

In relation to sanitation, the socio-cultural aspects ultimately focus on securing people's needs in an equitable way, incorporating human morality, relationships, and institutions (Warner et al. 2008; Wijk-Sijbesma 1998; SuSanA 2009). Balkema et al (2002) suggests that the examination of socio-cultural aspects builds upon human relations as well as the need for people to interact and develop themselves while organising their society. The socio-cultural aspects of a sanitation system are crucial since the sustainable operation or use and necessary service provision for the systems are dependent on human resource.

Therefore, the resolve that inclusion of people in sanitation planning, design, operation and monitoring is no longer considered optional, but has become a crucial component for successful and sustainable implementation of sanitation projects(Kvarnström et al. 2004; EAWAG-SANDEC 2005; Lüthi et al. 2011a; Lüthi et al. 2011b). Moreover, such assertions have been further confirmed by experiences, where rejection or abandonment of sanitation systems or projects has occurred. In such scenarios, the recipients of sanitation projects were often looked upon as beneficiaries whose concerns were neglected since the assessments were made based on "felt needs" rather than basing on user consultation (Lüthi et al. 2009; Parkinson et al. 2014; Andersson et al. 2016a).

In certain cases, the sanitation services provided did not reflect user preferences and this in turn negatively influenced the system maintenance while in other cases the sanitation systems were inappropriately used or totally rejected. This implies that the potential benefits from the rejected sanitation project are not ripped (Lüthi et al. 2009; Parkinson et al. 2014; Andersson et al. 2016a). Moreover, such oversights in the long run become extremely expensive, especially in cases where sanitation system replacement may be required as was the case in the ***Erdos Eco Town project.*** Here, an **EcoSan** sanitation system installed at residential apartments had to be replaced with the conventional flush toilet system due to user dissatisfaction, which was influenced by poor perception towards the **EcoSan** system (Qiang 2007; Jones et al. 2013).

Therefore, a general consensus exists amongst sanitation sector professional that for both equity and efficiency reasons, water and sanitation programmes/projects need to be responsive to people's felt needs and should also be based on their demands. Intrinsically, engagement of stakeholders at different levels of sanitation planning and implementation is promoted as cited in some of the sanitation approaches already discussed. However, to understand the needs of people, it is pertinent to appreciate that any relationship between people and their environment is embedded in their culture, which generally influences the way basics such as water or sanitation are conceived, valued and managed (Wagner 2003; Schelwald and Reijerkerk 2009). In relation to sanitation, the socio-cultural aspects are often distinguished under at least three main themes which include; cultural acceptance, institutional requirements, and perceptions towards sanitation.

Cultural acceptance of a sanitation system is underpinned by cultural beliefs regarding excreta, waste as well as water management and these beliefs vary widely in different parts of the world. According to Schelwald and Reijerkerk (2009), culture is considered a system of shared values, beliefs, behavior and symbols that members of society use to interact with their social surrounding. Understanding culture is therefore no easy feat since the appreciation of its core, which is manifested through beliefs, values, traditions, rituals, practices, artefacts and symbols is inevitable (Schelwald, and Reijerkerk 2009; Kvarnström et al. 2004). Schelwald and Reijerkerk (2009) suggest that culture consists of various layers as represented in Figure 4-1.

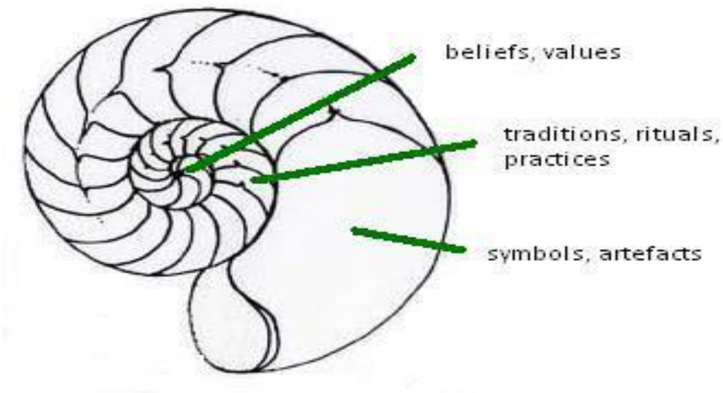

Figure 4-1: The Different Layers of Culture Symbolised by the Nautilus Shell
Source: (Schelwald and Reijerkerk 2009)

Moreover, culture is also transformed from generation to generation, implying that culture is dynamic (Schelwald and Reijerkerk 2009; Zion, Kozleski 2005). As such, adaptation of practices, especially with relation to excreta, wastewater, waste management and possibly reuse should be carried out with caution while incorporating the cultural aspects of specific communities or groups. In examining cultural acceptance of a sanitation system or project, gender aspects cannot be ignored since it is an important underlying factor in cultural considerations.

Gender identifies the social relationships between women and men, delineating the power differences hence, it plays a major role in influencing acceptance of sanitation systems. Gender is socially constructed while gender relations are contextually specific and often change in response to altering circumstances (Fong et al. 1996; Wijk-Sijbesma 1998; SuSanA 2009). It is often the case that provision of hygiene and sanitation services is considered a task for women although in contrast, societal decisions regarding sanitation programmes and projects may restrict women`s views (SuSanA 2009). Therefore, an in-depth understanding of the social and mental fabric concerning peoples` views towards handling and management of waste, water, excreta would further enlighten on the motivational factors influencing acceptance or rejection of a system (Drangert 2004; Vleuten-Balkema 2003).

Institutional requirements with reference to socio-cultural aspects are partly dependent on the inputs or waste streams to be managed in the sanitation system. The key questions related to "*how sanitation management is organised* and *if local organisations can be involved in the whole management chain*" mainly inform this stage (Schelwald and Reijerkerk 2009). Different sanitation systems require different regulations and control mechanisms. Nevertheless, these requirements should fit in the existing institutional infrastructure of the region or local area (Vleuten-Balkema 2003).

Thus, an institutional and regulatory framework is often necessary to ensure an enabling environment is created. Institutional framework basically refers to a set of formal organisational structures, rules and informal norms for service provision (refer to Chapter 3,). With reference to the water and sanitation sector, institutional framework should outline the responsibilities of water/sanitation services institutions, taking into consideration resource management and any necessary allocations in addition to monitoring and licensing services(IEES 2008; UNEP et al. 2004). Meanwhile the regulatory requirements give the necessary guidance for a sanitation project or intervention implementation.

Perception essentially considers the emotional response towards for example, excreta management or handling, which in most cases bears negative connotations while people`s perceptions towards water are often positive. As one of the components of attitude, perception reflects on the personal emotional connotations while cognition focuses on the thoughts, behavior and one`s tendency. All three components of attitude i.e. perception, cognition and behavioral tendencies are influenced by culture in some way (Schelwald and Reijerkerk 2009; Kvarnström et al. 2004).

Therefore, with reference to this background, this research considers two main criteria within the socio-cultural aspect and these include the acceptability of the integrated sanitation system by potential users and the institutional/regulatory requirements relevant for the sanitation systems. The acceptability of the integrated sanitation systems was based on user perception, which is inherently dependent on cultural values while the institutional/regulatory requirements are equally important given that the integrated sanitation system approach proposed considers combined management of organic waste streams with the additional goal of resource recovery. This implies that various entities or actors would be involved in the entire sanitation system value chain. As such, clear understanding of relevant institutions and regulatory requirements would be pertinent.

The output from the feasibility assessment of the four aspects discussed in combination with reference to the Helmholzt concept of sustainability informed the sustainability assessment of the integrated sanitation systems. Noteworthy was that overlaps between the four aspects, which were also considered the pillars of sustainability in this research were anticipated (Jörrisen et al. 1999; Gibson and Hassan 2005).

4.3 Sustainability Assessment

Sustainability impact assessment commonly referred to as sustainable assessment (**SA**) is defined as a

> "*systematic and iterative process for the ex-ante assessment of the likely economic, social and environmental impacts of policies, plans, programmes and strategic projects, which is undertaken during their preparation and where the stakeholders concerned participate pro-actively" (OECD 2008).*

Rather than adopting merely mitigation or minimisation of potential adverse environmental impacts, the **SA** approach is inherently integrative, participatory, positive and future-oriented. The overall goal of **SA** is to evaluate initiatives and programmes or projects with reference to sustainable development objectives while highlighting shortcomings and optimising the initiatives and programmes in question. **SA** incorporates a complete view of all aspects and promotes transparency in addition to including holistic considerations, which reflects the interdependency of aspects.

Moreover, reference is also made to the Helmholtz integrative concept to further inform sustainability assessment of the integrated sanitation system alternatives. The Helmholtz integrative concept translates the consecutive elements of sustainable development which include; the global perspective, justice postulate and the anthropocentric point of departure in to three general goals. The three general goals are; *securing human existence, maintaining society's productive potential and preserving society's options for development and action*. Thereafter, the concept concretises these goals by sustainability principles, which apply to various societal areas or to certain aspects in the relationship between society and nature. The principles have to be further concretised by suitable indicators which unfold the normative aspects of sustainability as goal orientation for future development and as guidelines for action (Grunwald 2012; Grunwald and Rösch 2011).

The final phase of the research includes suggesting a planning framework for the integrated sanitation system approach. Thus, a combination of input from all prior phases of the research and reference to other existing environmental sanitation planning tools informs this phase of the research. Figure 4-2 shows the conceptual framework of this research.

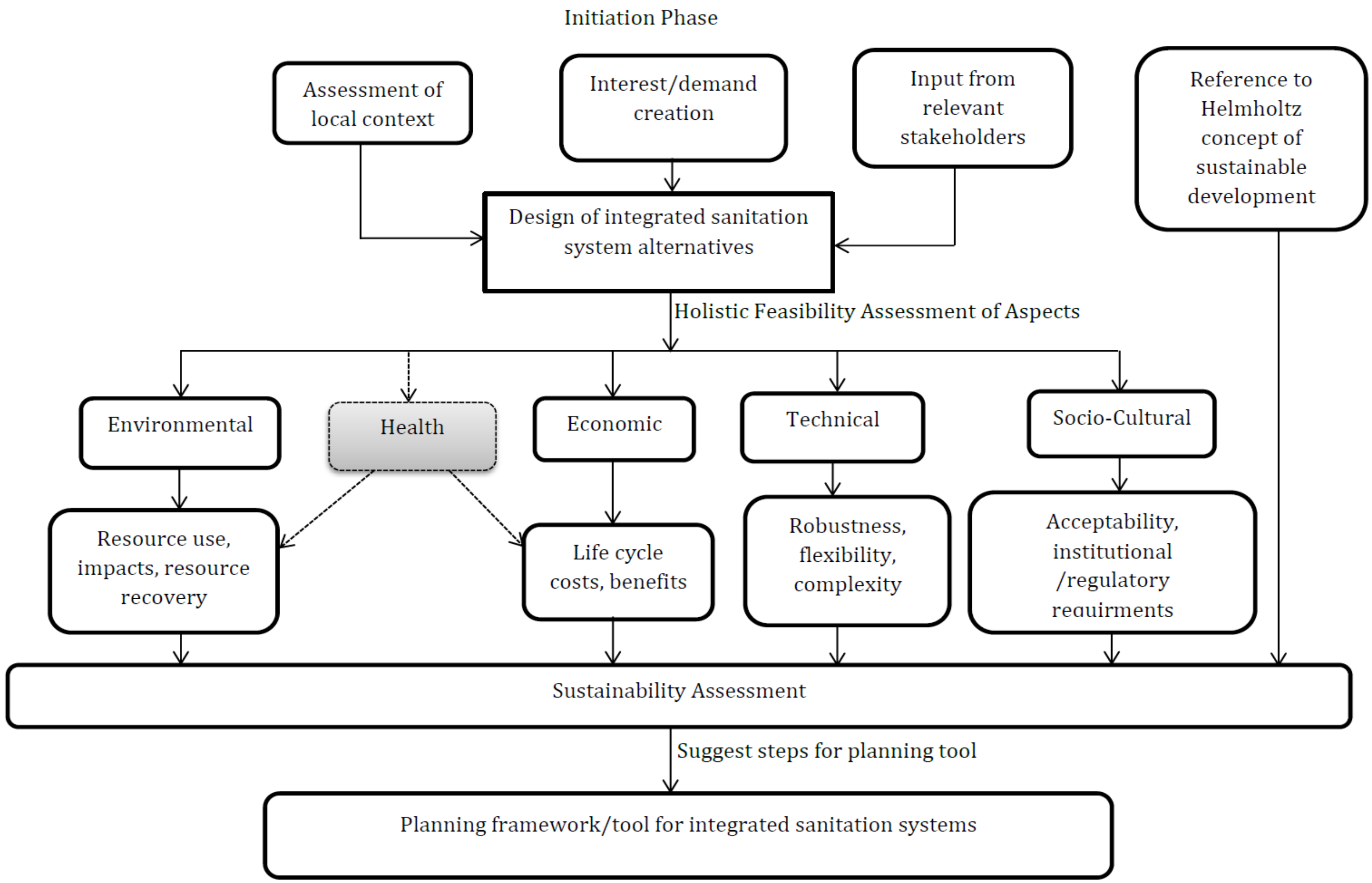

Figure 4-2: Conceptual Framework of the Research
Source: Author

In conclusion, this Chapter gives an overview of how the research is carried out. The conceptual framework highlights the purpose of the research, which is accomplished through four main phases. The phases include the initiation phase, which informs the design of integrated sanitation system alternatives, the feasibility assessment phase, sustainability assessment and the development of a planning framework for the integrated sanitation system approach. A discussion of the methods and tools used to accomplish the various phases of the research is detailed in Chapter 5 of this dissertation.

5 Research Methodology

Chapter 5 *presents the research methodology with reference to the research conceptual framework. The first Section of the Chapter discusses the research design, which includes a description of the research perspectives, case study approach considered and data collection tools used. Thereafter, a discussion of the methods considered to enable assessments within the various phases of the research is carried out.*

5.1 Research Perspective

This Chapter discusses the research methodology with reference to the conceptual framework already presented in Chapter 4 of this dissertation. Both quantitative[13] and qualitative[14] approaches were applied in this research and adoption of an evaluation research format, where judgment is typically undertaken to aid decision making was carried out. To fully appreciate the research, a case study approach was considered. Therefore, an empirical inquiry that investigated the contemporary phenomenon of the integrated sanitation system approach within a real life context was carried out (Yin 2014). Uganda Christian University, an institution of higher learning in Uganda was selected as the case study.

5.2 Case Study Approach

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin 1994). No claim is made for generalisability when considering a case study approach, it is rather about the quality of theoretical analysis that is allowed by intensive investigation into one or a few cases, and how well theory can be generated and tested using both inductive and deductive reasoning. Both quantitative and qualitative methods are appropriate for case study designs and often multiple methods of data collection are applied (Walliam 2006).

With reference to this research, the integrated sanitation system approach considered focuses on the management of organic waste streams from designated locations. As such, a single case design is considered for the integrated sanitation system approach with the aim of informing possible application of experiences obtained to other similar areas. Given that the selection of case studies needs not be a random activity, a two-step case study selection process was adopted (Yin 2014). These steps included; development of selection criteria and preliminary analysis of information regarding various options.

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[13] Quantitative research; lets researchers know and measure relationships between independent and dependent or outcome variables, providing the basis for predictions and typically results are represented numerically (Glatthorn and Joyner 2005).

[14] Qualitative research; bring deeper understanding to human behaviour and perception, emphasising a phenomenological view (Glatthorn and Joyner 2005).

5.2.1 Development of Case Study Selection Criteria

Criteria for selection of case studies vary and could depend on appropriateness and adequacy considerations among others. While appropriateness relates to demonstrating a "fit" to both the purpose of research and the phenomenon of inquiry, adequacy is concerned with how much is enough (Shakir 2002; Woodside 2010). Therefore, taking into consideration appropriateness and adequacy, criteria focusing on location, size and sectors involved among others can be considered. In this research, five main criteria are considered and are summarised in Table 5-1.

Table 5-1: Criteria for Selecting Study Area

Criteria	**Consideration/remarks**
Location	The study area should be located in a peri urban or urban area of a developing country, particularly in Sub-Saharan Africa. With reference to the characteristics of such areas already discussed in Chapter 3, increased growth is expected and there is high demand for various services including environmental sanitation.
Environmental sanitation	The case study area should have demand for environmental sanitation services. Specifically, an area encountering challenges in management of organic waste streams is recommended. The waste streams under consideration could include any combination of the following; organic solid waste, sewage and faecal sludge, animal excreta and wastewater effluent.
Demography	The study area should consist of a relatively high population density and positive growth rate. This would emphasise the requirement for sanitation services or necessary improvement in the future. A minimum population size of 1000 people can be considered since management of organic waste from such a population size could require adoption of variable approaches or combination of technologies/processes in addition to considerable stakeholder involvement.
Cooperativeness and engagement	Bearing in mind that planning and implementation of a sanitation approach will require considerable amount of data, stakeholder involvement and is an iterative process, stakeholder cooperation which is inspired by interest becomes an important factor in selecting a study area. Moreover, their engagement becomes a crucial factor in the implementation stage of the project as well.
Vulnerability/demand	The study area may additionally be vulnerable or require basic necessities such as energy, fertilizer for agriculture among others. Taking into account that the integrated sanitation system approach proposed in this research emphasises the resource recovery component, a study area which additionally requires basic necessities such energy or organic fertilizer would benefit much more from the integrated sanitation system approach. Therefore, an area with additional demand for resource recovered would be a good fit for the proposed approach.

Source: Author

Once the criteria were defined, a preliminary assessment of study options was carried out with the help of key informant interviews and questionnaires. This was aimed to further enable screening of options prior to final selection. Three case study options were analysed as briefly discussed in the following Section.

5.2.2 Preliminary Analysis of Case Study Options

National Housing and Construction Corporation Limited (NHCCL) - Uganda

Initially, National Housing and Construction Corporation Limited (**NHCCL**), Uganda was considered as potential case study area for the research. **NHCCL** is the government house construction arm, which provides for the housing demand in Uganda. **NHCCL** constructs housing estates in different parts of Uganda and this task is often initiated on un-serviced land. As such, **NHCCL** is mandated to develop infrastructure for electricity, water, and sanitation. These services, especially sanitation are decentralised and often times, **NHCCL** with the guidance of entities such as National Water and Sewerage Corporation (**NWSC**), manages the sanitation facilities of the respective estates.

In most cases, the housing estates could be home to at least 1,000 inhabitants and an opportunity exists for development of sanitation systems that could incorporate resource recovery. Moreover, these estates are often located in urban or peri- urban areas and in certain cases their development could be driving factors for the growth of small towns into urban centres. The mere fact that **NHCCL** is the responsible entity in such developments implies that all relevant decisions can be influenced by the entity and involvement of other stakeholders (occupants, potential customers etc.), especially during operation stage can be coordinated. Thus, with reference to this background, integrated sanitation systems for combined management wastewater and organic waste generated from housing estates could be considered. The overall goal of systems would be management to sanitation within the estate while additionally recovering resources in the form of biogas and organic fertilizer. However, despite having interest in the integrated sanitation system approach and fulfilling most of the criteria for selection, **NHCCL** cited financial challenges and limited capacity to support the research as key limiting factors for engagement. Thus, the cooperativeness/engagement criterion was not fulfilled.

Water and Sanitation Africa (WSA) - Burkina Faso

A similar proposal was suggested for **Water and Sanitation Africa (WSA)** housing estates in Burkina Faso**. WSA** is a Pan African inter-governmental agency providing continental leadership in the development of innovative and sustainable approaches, evidence-based policy advice and advocacy services in the provision of water, sanitation and hygiene services in Africa. **WSA** established the Enterprise and Investment Group (**EIG**) as one of her operational bodies to address the problem of pronounced disconnection between investors, lenders and end-users in Water Sanitation and Hygiene (**WASH**)**.** One of the main services implemented by the **EIG** component is integrated housing development, which also considers aspects of integrated sanitation management in future developments.

Similar to the **NHCCL** scenario, development of **WSA** housing estates in Burkina Faso includes infrastructural development for sanitation, water and energy. Moreover, the planned location of estates is in peri-urban and urban areas while an estimated population size of at least 1000 inhabitants is expected in the estates. However, similar to the **NHCCL** scenario, limited capacity to support the research was a key hindrance. In addition, much longer time frames required to confirm proposed case study sites and political unrest in Burkina Faso in the duration 2014-2015 affected selection of **WSA** as case study location.

Uganda Christian University (UCU) - Uganda

Uganda Christian University (UCU) is a private University located about 22km from Kampala, the capital city of Uganda. **UCU** like most institutions of higher learning in Uganda is mandated to manage her own waste. A full description of the University`s local context can be referred to in section 1.4 of this dissertation. However, brief discussion of **UCU** with reference to selection criteria developed is carried out here. The University has an estimated day time population of 6,000 and is located within Mukono municipality. Although the University has various sanitation measures in place, the final disposal of sewage sludge generated from the activated sludge wastewater treatment plant (**WWTP**) is currently a major challenge. There are also additional opportunities to manage kitchen waste from University kitchen and animal excreta from the farm.

UCU is heavily dependent on firewood for cooking and is interested in using cleaner energy sources such as biogas. The University`s strategic plan stipulates attaining environmental sustainability as one of the main goals. As such, improvement of sanitation management while recovering energy in the form of biogas from organic waste sources such as sewage sludge are some of the activities proposed to achieve environmental sustainability at the University. By implementing these activities, **UCU** expects to improve sanitation while additionally reducing dependence on utilisation of firewood for cooking purposes. The biogas produced from anaerobic digestion of sewages sludge is considered a clean energy source and would substitute firewood currently used. With reference to all three case study options considered, **UCU** fulfilled all the criteria for selection proposed and was chosen as the case study area.

5.3 Primary Data Collection Methods

Primary data collection methods mainly include specific techniques used to collect data with respect to the research problem (Glatthorn and Joyner 2005). During this research, empirical evidence, records from researcher's direct observation and experimentation, literature review and experience were key data sources. Data collection and interpretation methods were therefore crucial steps of the research and are elaborated in this section. A combination of both primary and secondary data sources was used.

Primary data; is considered original data focusing on the research problem at hand (Lancaster 2004). Primary data is closely related to and often has implications for the methods and techniques of data collection. In this research, primary data was collected by the researcher using techniques such as observation, interviewing, experimentation. Tools such as questionnaires and checklists further enhanced primary data collection.

Secondary data; is information which already exists in some form but was not initially primarily collected for the purpose or exercise at hand.(Lancaster 2004; Adams 2007). Most of the secondary data used in this research included, literature from various journal articles, books, reports, online data, and company/organization catalogues among others. Due to the wide variety of information required, several secondary data collection techniques were used.

5.3.1 Observation

Observation also referred to as "participant observation" or "ethnography" is an important element irrespective of the data collection method used. Observation consists of a mix of techniques ranging from; informal interviews, direct observation, participation in the life of the group, collective discussions, analyses of personal documents, self-analysis and transcripts among others (MacDonald and Headlam 2008; Adams 2007).

In this research, observation was used as a supporting method to validate information from relevant literature and capturing undocumented case specific information. The technique was also used to validate information compiled in questionnaires, interviews and experimental analysis discussed further in Chapter 6 of this dissertation. Through direct observation, information related to generation and management of waste, cooking energy utilisation and wastewater treatment at the case study area among others was ascertained. Furthermore, the technique was used in obtaining required operational information from faecal sludge treatment plants and institutional biogas latrines visited. Observations and interviews conducted allowed for comparative analysis of existing conditions such as: wastewater characteristics, daily operation and maintenance at various sites visited within and outside **UCU.** Figure 5-1 shows examples of application of observation as a data collection technique during the research.

	
Observation of briquette making from faecal sludge matter	Observation of continuous stirred tank experiment

Figure 5-1: Observation of various activities during the research
Source: Author

5.3.2 Interviews

Interviews are defined as discussions usually between an interviewer and an interviewee, which are carried out to gather information. During interviews, questioning of a specific set of topics to obtain information is often carried out (Lancaster 2004; Adams 2007). Interviews can be conducted in person or by use of other media i.e. telephone, skype interviews (Lancaster 2004; Adams 2007). Interviews were used in this research due to the flexibility and usefulness they offer in obtaining information and opinions from a wide variety of sources (Adams 2007). Three main types of interviews were employed i.e. structured, semi structured and unstructured. Each of these interview types has specific characteristics as summarised in Table 5-2.

Table 5-2: Summary of Interview Types and their Characteristics

Interview Type	Characteristics
Structured Interviews	• Often, an interview schedule is set and use of standardised questions, which maybe read out loud by the interviewer is common. • Since standardised questions are asked, the answers may be closed in format, i.e. specific response to query. • Such interviews are usually scheduled in advance at a designated time and location
Semi Structured interviews	• Considered the sole data source for a qualitative research projects • Contains structured and unstructured sections with standardised and open-format questions • Semi structured interviews are often scheduled in advance at a designated time and location
Unstructured Interviews	• Although no interview can be considered entirely unstructured, some are relatively unstructured and are more or less equivalent to guided conversations. • Use of a flexible format which is often based on a question guide is applied. • Often, the format remains the choice of the interviewer who can allow the interview to evolve so that insights into the attitudes of the interviewee are obtained • No closed-format questions are used and at times reference to observable data is made

Sources; (Lancaster 2004; Walliam 2006; Adams 2007; Yin 2014)

The interview types summarised in Table 5-2 were employed to obtain information from various stakeholders as noted in Table 5-3.

Table 5-3: Summary of Information, Sources and Interview Types

Information Sources	Type of Information	Interview Type
Government Institutions	• Roles and interests of institutions in biogas, and sanitation development. • Vision regarding biogas, sanitation and institutional framework development. • Existing support measures regarding sanitation, renewable energy and organic fertilizer • Implications of sustainable technology from institution's perspectives	Semi-structured Unstructured Unstructured Structured
Wastewater technology, faecal sludge, sanitation and biogas practitioners	• Assessment of technologies based on practitioner´s opinion • Sustainable technology perspectives from practitioners'	Unstructured Unstructured
Wastewater technology, faecal sludge, sanitation and biogas operators	• Operation measures in place • Assessment of technologies based on operator´s opinions • Sustainable technology perspectives from operator`s perspective	Structured Unstructured Unstructured
Users	• User benefits and challenges • User expectations of sanitation and biogas systems • Implications of sustainable technology from user(s) perspective	Semi-Structured Unstructured Unstructured
Experts in areas of sanitation, biogas and faecal sludge	• Framework conditions and applicability within Uganda • Future plans related to technology improvement	Unstructured

Source: Author

5.3.3 Questionnaires

Considered among the most widely used and valuable means of data collection, questionnaires were also used in this research. Questionnaires are *"any written instruments that present respondents with a series of questions or statements to which respondents are expected to react to either by writing out their answers or selecting from among existing answer" (Brown 2001).* Questionnaires can be either devised by the researcher or can be based on some readymade index (Mathers et al. 2007). Despite the wide application of questionnaires, they require a lot of time and skill to design and develop.

Moreover, questionnaires may limit the range and scope of questioning and the response rate can be low depending on various influencing factors (Walliam 2006; Lancaster 2004). During the research, questionnaires were used at different stages to gain insight into the following key areas; social and economic conditions, sanitation and solid waste management, biogas status within the country, agriculture and fertilizer demand as well as environmental awareness among others. Specifically, questionnaires were used to solicit information in three stages;

- At the initial stage of the research, a comprehensive picture of the study area, which included an understanding of sanitation and waste management measures, organic waste stream quantities within **UCU** and environmental awareness was required. Hence, staff and students within **UCU** were approached with questionnaires and relevant information collected. The outcome from questionnaire application at this stage informed experimental analysis and latter stages of the research, including design of integrated sanitation system alternatives.
- Questionnaires were also used to solicit stakeholder and expert opinion on sanitation systems alternatives, biogas technology application, fertilizer demand and institutional framework related to biogas technology and sanitation within the country. The data obtained contributed to the feasibility and sustainability assessment stages of the research.
- Finally, structured questionnaires were used to solicit information from stakeholders related to perception, acceptance and other social aspects in a survey discussed further in Chapter 10 of this dissertation. Moreover, elicitation of criteria and indicator information necessary for sustainability assessment of sanitation system alternatives was also obtained from stakeholders using questionnaires (refer to Chapter 11).

Two question formats were applied in the questionnaires used and these included;

- Closed-format questions; where the respondents chose from a given set of alternatives (Walliam 2006). This was mainly applied in the survey.
- Open-format questions; where the respondents could answer in their own words and style (Walliam 2006). This was applied both in the survey and other instances where questionnaires were used to collect information.

Questionnaire pre-tests were conducted prior to actual use, allowing for revision and necessary adjustments. The questionnaires were written and administered in English, which is the official language in Uganda. Most questionnaires were administered at respondents' places of work or study for **UCU** students, while other questionnaires were administered by email. This generally accorded respondents the comfort of expressing their opinions in familiar environments and in the absence of unnecessary interference.

5.3.4 Experimentation

The principle idea behind experimentation is to determine the effects of various factors on a response variable by varying these factors in a controlled way, and often in controlled conditions (Adams 2007; Lancaster 2004; Glatthorn and Joyner 2005).

Experimentation can be a very reliable and effective means of collecting data and verifying or refuting theories. In this research, experimentation was used in characterisation of organic waste streams from **UCU.** Furthermore, bio methane potential (**BMP**) and continuous stirred tank reactor (**CSTR**) experiments of the organic waste streams were carried out at Flensburg University of Applied Sciences**(FUAS)**, Germany and **UCU** laboratories. The **BMP** experiments were carried out to evaluate the anaerobic biological degradability of the organic waste streams while the **CSTR** experiments informed anaerobic digestion process optimisation (VDI 2006; Usack et al. 2012). A detailed discussion of the experimental analysis is included in Chapter 6 of this dissertation.

5.4 Generic Steps of the Research

With reference to the research conceptual framework in Chapter 4, the research was divided into four main phases which included; initiation, feasibility and sustainability assessment and finally tool development phase.

5.5 Initiation Phase

During this phase, identification of areas where sanitation improvement was required was carried out and this helped to clarify on the interests of **UCU**. During this process, preliminary identification of various stakeholders was also carried out, allowing for soliciting of additional information. Based on the University`s interests and intended goals already mentioned, **UCU** acted as an own champion for improved sanitation. Moreover, during this phase, a detailed assessment of the local context, which included **UCU** and her surrounding, was also carried out. The assessment enabled better understanding of the local context, taking into consideration the existing physical and socio-economic environment of the designated areas. The detailed assessment also included a participatory approach, which took into account elements of environmental sanitation, particularly organic waste management and the views or experiences of the community. Moreover, a full assessment of the enabling environment, reflecting on issues such as sector legislation and regulations, availability of human resources and skill levels, required material, sector finance among other was carried out.

This assessment phase was also further informed by the experimental analysis of the organic waste streams identified at **UCU** as already mentioned. It should be noted that the experimental analysis of organic waste streams from **UCU** was carried to ensure that specific information regarding the waste streams was obtained. Although in cases where experimental analysis is not feasible, reference to relevant literature can also be considered. Based on the detailed assessment of the local context carried out as well as stakeholder input, linkages between components and elements of environmental sanitation services were identified. This in turn led to the preliminary design of integrated sanitation system alternatives proposed for **UCU**. Further screening of integrated system alternatives was carried out by the researcher with guidance from experts and reference to relevant literature.

5.6 Feasibility Assessment Phase

Feasibility assessments are conducted to obtain an overview of the problem and to roughly assess whether feasible solutions exists prior to committing substantial resources to a project. Feasibility assessments, which are also referred to as preliminary investigations are often seen as an important source of information in planning and implementation of sanitation systems (Andersson et al. 2016a; Overton 2007). Often used as analytical tools during business development processes, feasibility assessments show how a business or project would operate under a set of assumptions. Typically, these assessments comprise of: technical, economic, legal, operational, cultural and schedule aspects (Overton 2007; USDA 2010). The application of feasibility studies is quite broad since they are often considered a requirement for obtaining funding and establishing projects.

As initially noted in the conceptual framework, four aspects which include the technical, environmental, economic and socio-cultural are considered. As such, the feasibility assessment of the integrated sanitation system alternatives proposed for **UCU** would be carried out based on the selected aspects. For each of the feasibility assessments carried out, different methodologies were selected and used as discussed.

5.6.1 Technical Feasibility Assessment

In assessing the functionality/technical aspects of sanitation system alternatives, robustness, flexibility and complexity of the system are considered as indicated in the conceptual framework. Often the case, checklists consisting of critical questions can be used to assess technical aspects of technologies proposed or used in a sanitation system (Zurbrügg 2013). In other instances, questionnaires are also used to obtain necessary information on system functionality. In this research, a combination of checklist and questionnaires were used to obtain necessary information related to sanitation system functionality. Moreover, a strength(S), weaknesses (W), opportunities (O) and threats (T) (**SWOT**) analysis was additionally carried out to further inform the technical feasibility assessment.

SWOT analyses are often carried out as precursors to strategic planning and could be performed by variable groups i.e. researchers, organisations, experts etc. with the aim of making an assessment often from a critical perspective. **SWOT** analysis basically examines the internal strengths and weaknesses while incorporating the external environment which is reflected by the opportunities, and threats. A **SWOT** analysis has four steps, which may generally include; collection and evaluation, sorting of the data into four categories i.e. strengths, weaknesses, opportunities and threats. A **SWOT** matrix is then developed with the aim of giving a broader perspective to the feasibility assessment findings (Gretzky 2010; Valentin 2001; Houben et al. 1999; Bull et al. 2016). The idea of **SWOT** analysis has its roots in strategic management research conducted in the 1960`s and is commonly linked to Albert Humphrey as one of the initial authors.

SWOT analysis is based on the perspectives that the performance of a specific agent i.e. project, business or sanitation system with respect to a particular objective, depends on the way in which the management of that agent interacts with both the internal characteristics of the agent and the broader external context in which the agent must act. Basically, the aim of any **SWOT** analysis is to identify the key internal and external factors that are important in achieving the specific objective of a business, project or sanitation system in this case. **SWOT** analysis groups key pieces of information into two main categories i.e. the internal factors which consist of '*strengths*' and '*weaknesses*' and external factors which are basically the `opportunities' and 'threats` (Valentin 2001; Bull et al. 2016; Houben et al. 1999). Once grouping of information is completed, the **SWOT** analysis determines what may assist in accomplishing the objectives of a sanitation system for instance and what obstacles must be overcome or minimised to achieve the desired results. Further discussion of the technical feasibility assessment for the integrated sanitation system alternatives proposed for **UCU** is included Chapter 7 of this dissertation.

5.6.2 Environmental Feasibility Assessment

In this research, the environmental feasibility assessment takes into consideration the resource use, impacts on the environment and resource recovery from the integrated sanitation system alternatives. Common methods of assessment of environmental feasibility of sanitation systems include environmental impact assessment **(EIA),** material flow analysis **(MFA**) and life cycle assessment (**LCA**) among others.

5.6.2.1 Environmental Impact Assessment (EIA).

EIA is a decision-making tool used to identify potential environmental impacts of proposed projects, to evaluate alternative approaches, and to design and incorporate appropriate prevention, mitigation, management and monitoring measures (FAO 2012; Abaza et al. 2004; Wrisberg et al. 2002). Often considered at the early stage of projects, **EIA`s** have been applied for various projects ranging from agriculture, infrastructural developments, to water and sanitation to mention but a few(NWSDB 2012).

Despite early application dating back to the 1970`s, **EIA** was not readily accepted in developing countries based on the arguments that the tool was considered a stumbling block to development. The initial focus of **EIA** application for industrial development partly contributed to the negative connotation attributed to the tool with reference to development in developing countries. The “stringent” requirements of **EIA** were associated with requirements from industrial development rather than local oriented development (Achieng 2007; Abaza et al. 2004). However, these notions have slowly changed, especially with environmental and social impact assessments, which are often considered additional requirements for obtaining funding for project development from entities like World Bank (Abaza et al. 2004).

5.6.2.2 Material Flow Analysis (MFA)

MFA method is rooted in system analysis and is defined as a systematic assessment of the flows and stocks of materials within a system defined in space and time(Brunner and Rechberger 2004; Wrisberg et al. 2002).

MFA connects sources, pathways, intermediates and the final sinks of a material and the method is strongly linked to the law of the conservation of matter. As such, the results of **MFA** can be controlled or varied by a simple material balance comparing all inputs, stocks, and outputs of a process. The methodology has proven to be a suitable method and tool for the early recognition of environmental problems and the development of mitigation measures (Barrett et al. 2002; Montangero 2006; Dahlman 2009). With the first studies of its application in resource conservation and environmental management traced back to 1970s, **MFA** has been used to reflect changes in consumption patterns.

MFA has also been used to reflect reuse practices in solid waste and wastewater, peri-urban agricultural production, and environmental pollution patterns among others (Barrett et al. 2002; Chang et al. 2007; Zurbrügg 2013). Despite this broad application of **MFA**, the underlying reality is that data uncertainty has to be dealt with to ensure that the findings are considered reflective and useable (Danius 2002).

5.6.2.3 Life cycle assessment (LCA)

LCA is defined as *a technique for assessing the environmental aspects and potential impacts associated with a product or process by;*

- *Compiling an inventory of relevant inputs and outputs of a product system*
- *Evaluating the potential environmental impacts associated with those inputs and outputs*
- *Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (ISO 1997; Owens 1997; Helias et al. 2005).*

LCA has been extensively applied for environmental assessment under the broad themes of design for the environment exercises, marketing claims and Eco labels, government policy, in addition to water and sanitation system analysis (Remy 2010; Cherubini et al. 2009). Despite the extensive application of **LCA** dating back to the 1960`s, the methodology has drawbacks which include;

- Requirement of large amounts of data,
- Aggregation of results into impact categories implies certain information may be lost in the process
- The fact that assessment is confined by the system boundaries, implies that changes within the system, e.g. in demand may not easily be accounted for, limiting assessment (Owens 1997; Helias et al. 2005).

In this research, the **LCA** methodology was selected for assessment of environmental feasibility of the integrated sanitation system alternatives. **LCA** was chosen because of its comprehensive and holistic nature, allowing for “cradle to grave” assessment (Wrisberg et al. 2002). This characteristic of **LCA** limits the shifting of problems within a system assessed to another phase.

Moreover, in comparison to **MFA** and **EIA**, **LCA** is quite comprehensive since an **LCA** approach is used when carrying out **MFA** while the impact assessment component is included in **LCA**. Furthermore, **LCA** offers the opportunity to evaluate sanitation system alternatives while considering all three criteria of resource use, impact assessment and resource recovery. The tool allows for distinct representation of effects of resource use and resource recovery as well as impacts to the environment. Moreover, specific categorisation of these impacts can be achieved in **LCA**. Thus, representation of impacts to the environment such as eutrophication due to discharge of untreated effluents or sewage sludge and the discharge of heavy metals from untreated sewage sludge represented as toxicity potentials can be achieved using **LCA.**

LCA is standardised by the **ISO 14040** series and it mainly comprises of four phases namely; goal and scope definition; inventory analysis; impact assessment and interpretation as shown in Figure 5-2.

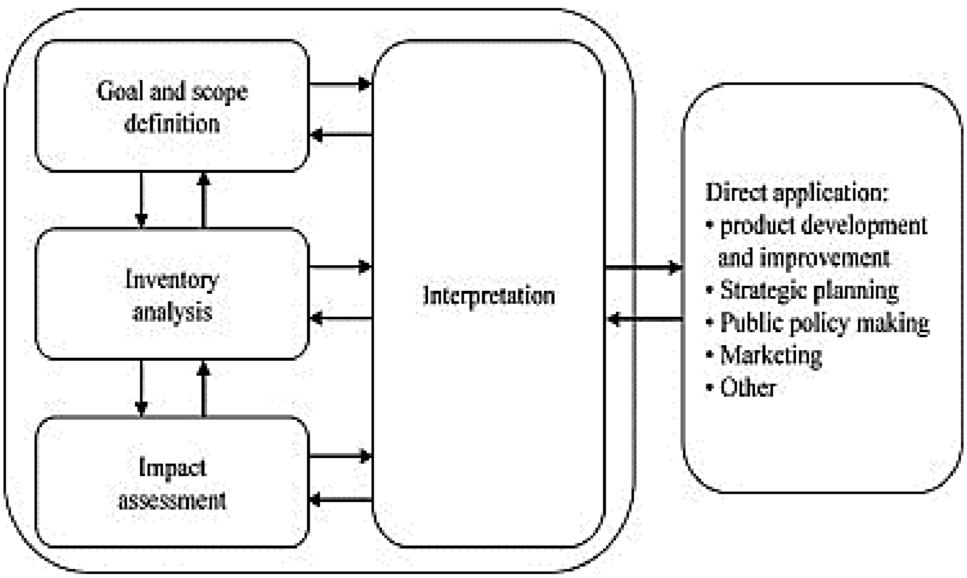

Figure 5-2: LCA framework
Source: (ISO 1997)

The goal and scope definition; is an important phase of **LCA,** where the purpose of the assessment is defined. Information regarding the intended application of the study, focus audience, the expected product or process, system boundaries in addition to the functional unit, assumptions, limitations and types of impact are taken into account at this stage. Moreover, the methodology of impact assessment and data requirements among others should be clearly stated in this phase since will help lay the basis of the rest of the study (ISO 1997; DEAT 2004; Jensen et al. 1997; DEAT 2004).

The inventory Analysis; involves data collection and calculation procedures to quantify relevant inputs and outputs of a product, activity or system in relation the functional unit of the study. The inputs and outputs may include the use of resources and emissions to the environment, which are associated with the system. Inventory data also constitutes inputs to the life cycle impact assessment hence, the inventory analysis phase forms the core of an **LCA** and is considered the most time consuming phase. During data collection and computation, allocation procedures may be applied, especially in cases where multiple products and energy flows are involved (ISO 1997; Jensen et al. 1997; Helias et al. 2005).

The life cycle impact assessment (LCIA) phase; aims at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. In most cases, the inventory results are assigned to different impact categories based on the expected types of impacts on the environment. Ultimately the level of detail, choice of impacts evaluated and methodologies used depend on the goal and scope of the study. The **LCIA** phase may thus include; assigning of inventory data to impact categories and this known as classification. Also, modeling of the inventory data within impact categories takes place in this phase, which is referred to as characterisation. Moreover, weighting which involves aggregation of results may also be carried out in this phase (ISO 1997; Jensen et al. 1997; Helias et al. 2005).

The interpretation phase; here the findings from the inventory analysis and the impact assessment are combined to give conclusions and recommendations to decision-makers. The conclusions and recommendations given should be consistent with the goal and scope of the study. However, in cases where only the life cycle inventory studies are carried out, the findings of only the inventory analysis are used to generate recommendations (ISO 1997; Jensen et al. 1997).

5.6.3 Economic Feasibility Assessment

With reference to sanitation interventions or projects, attempts to link impacts of poor sanitation to economic losses while at the same time assessing economic returns associated with reducing the burden of health, environmental issues and even citizens' lost time and productivity are often considered. Therefore, the economic assessment of the sanitation system alternatives takes into consideration the related life cycle costs and benefits. With reference to such assessments, some of the commonly applied methods include; cost effectiveness analysis, life cycle costing and cost benefit analysis among others.

5.6.3.1 Cost Effectiveness Analysis (CEA)

This method basically compares policy, project or program costs relative to their outcomes, and indicates which option produces a desired outcome for the lowest cost. The method can only compare those programmes or projects that have the same types of outcomes (Wholey et al. 2004; Henrichson 2014; Gift and Marrazzo 2007). The key principle of **CEA** considers a combination of the net cost of a given intervention and the outcomes with its effectiveness.

Application of **CEA** is useful in cases where major outcomes are either intangible or otherwise difficult to monetise. However, the main difficulty with **CEA** is that the method provides no value for the output, leaving the burden to the subjective judgment of the policymaker or decision maker (Wholey et al. 2004). Both **CBA** and **CEA** have been extensively applied even in sanitation related projects (GDN 2013; Gift and Marrazzo 2007).

5.6.3.2 Life Cycle Costing (LCC)

LCC *is defined as the total ownership cost of a product or process through its useful life* (Farr 2011). The technique enables comparative cost assessments to be made over a specified period of time, considering all relevant economic factors both in terms of initial costs and future operational costs. Determination of **LCC** is important for systems because the acquisition is just part of the whole chain since the true or total costs associated with maintenance and operation are equally important. The **LCC** technique is considered quite mature with applications dating back to the 1970`s and it has been extensively used in regions like Europe, where it has attracted attention in the public sector (Ciroth et al. 2008). Increasingly, follow-up costs are allowed or prescribed in public projects, infrastructure and procurement activities, although notable application in sanitation also exists (Burr and Fonseca 2011; Reddy et al. 2013).

Despite the extensive application of **LCC**, the method has some limitation which include; negligence in internalisation of external costs which are not borne directly by any of the life cycle actors in question. Additionally, if the boundaries are not defined, the scope of **LCC** may become impossible to manage, adding to complexity in application. Such challenges have often resulted in negligence of certain phases of the life cycle such as “end of life” operations (Ciroth et al. 2008; Reddy et al. 2013).

5.6.3.3 Cost Benefit Analysis (CBA)

CBA seeks to take into account as far as possible, all costs and benefits associated with a specific project or programme (Wrisberg et al. 2002; Pearce et al. 2006). In so doing, **CBA** provides a consistent procedure for evaluating decisions in terms of their consequences. **CBA** is based on the foundations of benefits defined as increases in human wellbeing and costs as reductions in human wellbeing, both of which are computed in monetary terms. Currently recognised as the major appraisal technique for public investments and public policy, **CBA** enjoyed fluctuating application since the 1960s(EC 2015).

CBA has a very broad scope and aims at expressing all positive and negative effects of an activity in monetary terms and this is often considered from a social point of view. The key methodological steps in **CBA** include; determination of which costs and benefits are examined, identification of the costs and benefits and finally weighing the costs and benefits against each other(Wrisberg et al. 2002; Brent 2006). Notwithstanding **CBA`s** overall goal of attaching monetary value to all aspects of a project or programme, the practicality of this task may be difficult in certain cases. Therefore, the reliability of the **CBA** decision rules depends on the comprehensiveness of the monetisation stage.

Excluding important effects or monetising them incorrectly can lead to the choice of projects or programmes that do not promote efficiency and this is one of the limitations of **CBA** (Weimer 2008). For certain projects, especially in the infrastructural sector, efficiency can be reasonably taken into account as the relevant values and all major impacts can be confidently monetised. This may however not be the case for other projects where the social function is fundamental.

Therefore, **CBA** is criticised for its dependence on robust theoretical foundations and the fact that the "social welfare function" in **CBA** has to be chosen among an arbitrarily large number of such functions on which consensus is unlikely to be achieved (Pearce et al. 2006). Moreover, aggregating social welfare costs and benefits maybe an uphill task, especially when this is carried out over an extended duration of time. The variability in costs and benefits often existing in the various time horizons can be a limitation to the process of aggregation. As such, even though discounting future amounts and converting them to their equivalent value today, or "present value is commonly practiced in **CBA**, the process is not without limitations.

In cases where the time span is so great that different generations are involved in costs today and benefits tomorrow, which can be assumed when sustainability aspects are considered, discounting may be problematic. In such cases, the analogy to make decisions on an individual investment with reference to the financial transactions anticipated may break down (Ackerman 2008; Crespi 2011) This is also because discounting may include different values for each purpose and stakeholder(s). This is partly because the appropriate discount rates have to be used in the discounting process. However, the discount rates cannot be decided ethically or scientifically but maybe influenced politically, albeit in accordance with scientific information and ethical orientation (Pearce et al. 2006; Grunwald 2012). Consequently, these key limitations of **CBA** have to be considered, especially for projects such as the sanitation systems proposed in this research, which would have a life time of at least 20 years.

Moreover, the application of **CBA** maybe marred with challenges in regards to environmental related projects, where for example difficulty may arise in attaching monetary value to environmental assimilative capacity or other biological effects such as pathogen reduction (Ackerman 2008). Another significant limitation of **CBA** is that it ignores distributional issues, including whether those who care about the benefits of the project can actually afford to pay for it.

In spite of the criticisms noted, **CBA** is still considered a comprehensive analytical tool since various parameters can be used to compare costs and benefits. These parameters include; Net present value, payback period and the internal rate of return among others

The ***Net Present Value*** **(NPV)** is the sum of all cash flows discounted for the given duration thus, the time value of money is recognised. Projects whose returns show positive **NPV**s are considered attractive with a higher **NPV** value indicating profitability of the project.

The advantage of **NPV** computation is recognised by the fact that is can be easily added. Moreover, the time value of the money is additionally catered for in **NPV** computations. As such, **NPV**s of different projects can be summed up and the total benefits from the implementation of more investments can be quantified. However, the disadvantages of **NPV** include the difficulty in determining the discount rate. Furthermore, since **NPV** is an absolute variable, it does not express the accurate rate of profitability. Nevertheless, for projects where a discount rate is availed, computation of **NPV** is simplified (Brent 2006; Yiridoe et al. 2009; Karellas et al. 2010).

The ***Internal Rate of Return*** (**IRR)** is defined as the discount rate at which the after-tax **NPV** is zero. Hence, the present value of the investment funds equals the net present revenues from operation. The main advantage of the **IRR** is that unlike **NPV**, the percentage results allow projects of different sizes to be easily compared. Thus, application of the **IRR** parameter in determining acceptance or rejection of a project is simple. If the project`s **IRR** is higher than the capital cost, then project is accepted otherwise it should be rejected. The higher the **IRR** or the more it surpasses the required project productivity, the more profitable the project is (Karellas et al. 2010; Brent 2006).

The ***Payback Period*** (**PBP)** computation basically compares revenues with costs and determines the duration required to recoup the initial investment of a given project. A dynamic payback period is calculated without regards to the time value of money. The **PBP** is frequently used to analyse retrofit opportunities, offering incremental benefits and end-user applications (Yiridoe et al. 2009; Karellas et al. 2010).

In this research, **CBA** in combination with the various parameters for computation of net present value, benefit cost ratio and the rate of investment are applied for assessment of the economic feasibility of the integrated sanitation systems. This methodology was preferred to **CEA** and **LCC** because it considers assessment of both the benefits and life cycle costs. **CBA** offers the opportunity to incorporate not only the potential economic losses from poor sanitation, but also the economic returns associated with reducing the burden of health from improved sanitation as well as reducing the environmental impacts. Moreover, citizens' lost time and productivity as a result of poor health associated with poor sanitation can be translated into cash flows, making the business case for the various sanitation system alternatives compared.

In so doing, the important effects attributed to sanitation are included while additionally incorporating the "social welfare" function, which is reflected through assessing the reduced burden on health of potential sanitation system users and reduced environmental impacts. Moreover, to check the discounting problem associated with possible changes due to extended time spans, sensitivity analyses are also carried out to reflect the possible discount rates for instance. With reference to the limitation associated with ignoring distributional issues, the involvement of relevant stakeholders, including potential system users during the planning and implementation stages could solve this limitation.

Already, such approaches are suggested in environmental sanitation approaches such as the community led urban environmental sanitation (**CLUES)** and Household- Centered Environmental Sanitation **(HCES)** discussed in Chapter 2 of this dissertation. Therefore, it is against this background that **CBA** is preferred as a tool for economic feasibility assessment of integrated sanitation system alternatives in comparison to **CEA** and **LCC**. Further discussion of the economic feasibility assessment is included in Chapter 9 of this dissertation.

5.6.4 Socio-Cultural Feasibility Assessment

Given that the socio-cultural aspect in this research takes into consideration the sanitation system acceptability and institutional/regulatory requirements, an initial and critical stage is to ensure that stakeholder identification and analysis is achieved. Interactions with stakeholders can then be carried out prior to structuring of the socio-cultural assessment (Zurbrügg 2013). The common tools used to enable proper stakeholder identification while appreciating their interrelations are social network analysis and stakeholder analysis.

5.6.4.1 Social Network Analysis

Social network analysis is a method based on the assumption that relationships among interacting units are important. Social network analysis is seen as a complementing tool to stakeholder analysis (Wasserman, and Faust 1994). Also, social network analysis is said to encompass theories, models, and applications that are expressed in terms of relational concepts or processes. The tool can be used to study the process of change in a group which could happen over time. Social network perspective has a distinctive orientation in which structures, their impact, and their evolution become the primary focus. Thus, since structures may be behavioral, social, political, or economic, social network analysis allows a flexible set of concepts and methods with a broad interdisciplinary appeal(Lienert et al. 2013).

5.6.4.2 Stakeholder Identification and Analysis

Stakeholder analysis is defined as a process of systematically gathering and analysing qualitative information, to determine whose interests should be taken into account, when developing and/or implementing a project, programme or policy (Schmeer 1999.; Babiuch, and Farhar 1994). Stakeholder analysis is a powerful tool that helps to identify and prioritise stakeholders who may have an impact on the project. The tool is an essential starting point for understanding critical stakeholders and developing engagement strategies for building and maintaining the networks which could be necessary for the delivery of successful project outcomes.

Stakeholder analysis is deemed an important stage in any participatory exercise (Schmeer 1999.; Babiuch, and Farhar 1994). Reed et al. (2009) suggest that a stakeholder analysis might typically proceed through the three phases of context definition, application of stakeholder methods and recommendation of necessary actions. These three phases are further divided in to six steps as shown in Figure 5-3 .

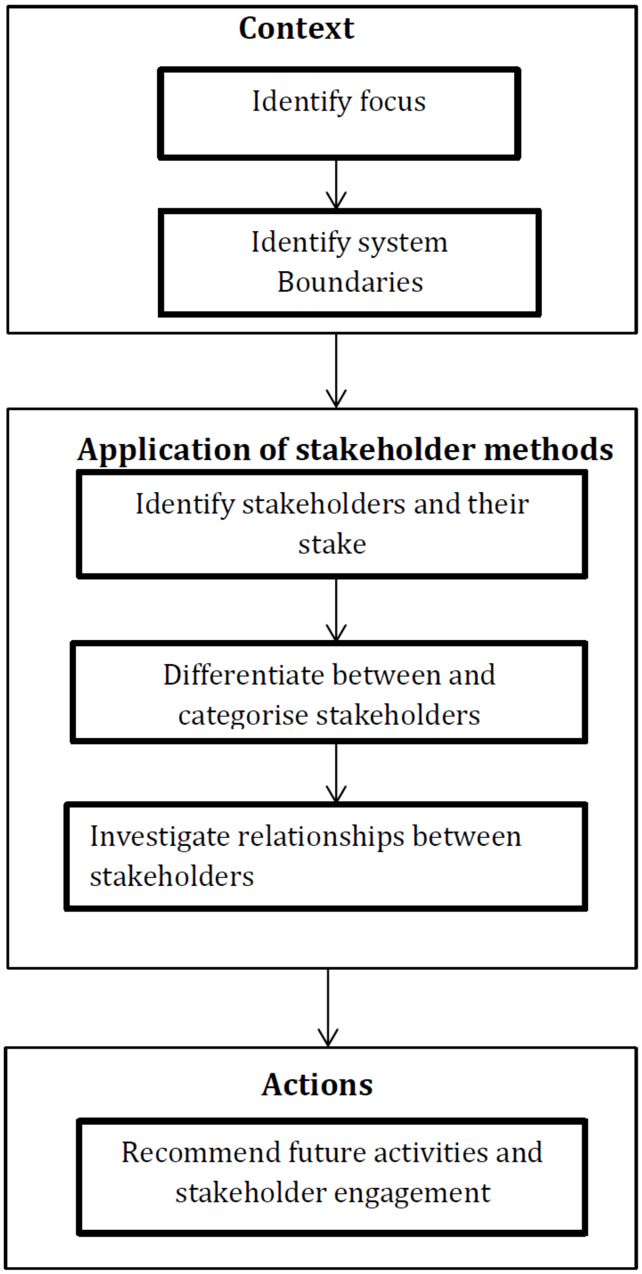

Figure 5-3: Necessary steps for Stakeholder Analysis
Source; (Reed et al. 2009)

The outcomes from the initial stages of stakeholder analysis inform the identification of stakeholders, which is imperative for the success of the analysis. The identification stage involves evaluation of stakeholder characteristics, giving details with regards to their interests and influences. This results in development of a list of priority stakeholder groups. Examples of stakeholders can be specific organisations, governmental agencies or authorities (Schmeer 1999.; Babiuch and Farhar 1994). Once the required information is obtained, analysis is carried out and recommendations from the analysis given.

However, it should be noted that stakeholder analysis is usually an iterative process since people`s interests and influence could change over time. Despite assertions that stakeholder analysis is a holistic procedure for gaining understanding of a system, critics point out that application of the tool in the narrow sense is often done on an ad-hoc basis. This implies that the fulfillment of a holistic approach may be compromised. Stakeholder analysis is also criticised as lacking to a certain extent with reference to analytic quality and academic rigor since there seems to be considerable confusion over the concept of stakeholder analysis and its practice (Brugha 2000)

Given the scope of the integrated sanitation system approach proposed in this research, a comprehensive understanding of the sanitation system can only be achieved once the local context and the related impacts are taken into consideration. Moreover, by the mere fact that combined management of various organic waste streams is expected and that resource recovery is anticipated, numerous stakeholders or actors can be expected. As such, understanding the interests, power and roles of various stakeholders involved within the integrated sanitation system value chain is extremely important for the operation and or longevity of the sanitation systems. Such a task can be accomplished with the help of stakeholder analysis, which not only enables the identification of stakeholders, but additionally analyses the interrelations or connections between them. Moreover, by analysing relevant information from the stakeholders, networks are also identified. Thus, a social network analysis may not really be required.

Therefore, in this research, the findings from the stakeholder analysis are expected to further inform the socio-cultural assessment. As such, the acceptability of the integrated sanitation system alternatives can be investigated using surveys to examine perception or attitude of potential user`s or selected stakeholder groups identified during the stakeholder analysis stage.

5.6.4.3 Surveys

Surveys essentially involve collection of data from large numbers of respondents and can take various forms including for example full-scale censuses, looking for descriptive data, exploring relationships between variables and searching for analytical data. Often the case, surveys of whatever form and purpose use questionnaires for collection of necessary information (Lancaster 2004; Mathers et al. 2007; MacDonald, and Headlam 2008). Surveys are widely applied in variable fields, including business management, social sciences, education, sanitation among others. Nevertheless, application of surveys is also limited by the response rate to surveys, which could affect its representativeness. The crucial aspect of survey representativeness has resulted in some researchers being content if 20 % of the people respond to their survey. Despite this generalisation, the remaining 80 % of the respondents are often not accounted for (Adams 2007; Mathers et al. 2007). Moreover, the costs related to running surveys could further limit its application, especially in cases where large sample sizes are required.

Once a stakeholder survey is carried out to determine sanitation system user acceptability, additional information related to the institutional and regulatory requirements will be reviewed so as to understand the enabling environment. Chapter 10 gives a detailed discussion of the Socio-Cultural assessment of integrated sanitation systems with reference to the case study. Having carried out a holistic feasibility assessment, the findings from the assessment are expected to inform sustainability assessment of the integrated sanitation system alternatives.

5.7 Sustainability Assessment

In comparison to other assessment methods such impact assessments, **SA** incorporates a complete view of all aspects and promotes transparency in addition to including holistic considerations, which reflects the interdependency of aspects. As such, **SAs** may be considered complex although they are usually conducted for supporting decision making in a broad context (Sala et al. 2015). **SA** has been applied in different fields ranging from technology, infrastructure, sanitation to mention but a few and this implies that various tools have also been applied to enable **SAs** (UNEP 2012; Lennartsson 2009).

Sala et al. (2015) generally suggest the following phases are necessary when carrying out **SA**;

- identification of the most suitable assessment methodologies (i.e. related methods, models, tools, and indicators);
- Sensitivity and uncertainty analysis of the assessment framework;
- Definition of monitoring strategies to track progress towards sustainability.

The fact that different aspects are often considered in **SA** implies that no single method can be used for assessment. Often the case, a combination of different methods, models and indicators are necessary to accomplish **SA** (Sala et al. 2015). In this research, a combination of methods is also used to enable the sustainability assessment. Given that the integrated sanitation system approach suggested in this study adopts a holistic stance, which basically incorporates the sustainability approach, the results from the feasibility assessments are expected to inform the sustainability assessment.

Moreover, reference is made to the Helmholtz integrative concept of sustainable development discussed in Chapter 2 and 4 to further enable sustainability assessment. Given that by combining different methods, challenges may arise related to; feasibility and meaning, robustness of results, how to address uncertainty, how to ensure replicability or comparability and transparency, multi-criteria decision analysis **(MCDA)** methodology is applied for the **SA** (Sala et al. 2015). The **MCDA** methodology enables structuring of complex problems and allows for aggregation of methods.

5.7.1 Multi-Criteria Decision Analysis (MCDA)

MCDA methods are designed to support decision makers in their decision process and often take into consideration the various criteria guiding decision making (Ishizaka and Nemery 2013). **MCDA** is described *as "a collection of formal approaches which seek to take explicit account of multiple criteria*[15] *in helping individuals or groups explore decisions that matter"* (Belton and Stewart 2002).

MCDA distinctly places the decision maker at the center of the process, offering a stepping-stone and techniques for finding a solution based on compromise. In principle, the foundation of **MCDA** is anchored on decision makers establishing objectives and criteria, then estimating relative importance weights and to some extent judging the contribution of each of the options to the performance criteria (DCLG 2009; Belton and Stewart 2002). As a tool, **MCDA** encompasses mathematics, management, informatics, psychology, social science and economics disciplines. This allows for the comparison of variable aspects or components which may have additionally have different units. For instance environmental and economic aspects maybe compared using **MCDA**.

MCDA techniques can be used to identify a single most preferred option, or used to rank options and short-list a limited number of options for subsequent detailed appraisal or it can simply be used to distinguish acceptable from unacceptable possibilities (DCLG 2009; Belton and Stewart 2002). Given that decision makers are often involved in the process and that experts involved may also have varying opinions based on the topic at hand, subjectivity can definitely not be avoided in **MCDA** although it can be managed. In addition, the fact that **MCDA** does not give a "right" answer implies that the tool cannot show that an action adds more to welfare than it detracts. Thus, the 'best' option could be inconsistent with improving welfare and this could imply that a "No Action" option could in principle also be preferable (DCLG 2009).

MCDA has been widely applied in various fields which include; structural development, technology assessment, energy assessments, risk assessment for land use, water, waste, sanitation, management among others (Velasquez and Hester 2013). This wide spread application of **MCDA** has also led to the development of additional methods further informed by research in the field. Moreover, various **MCDA** frameworks have also been developed with the aim of evaluating options using systematic analyses, which overcome the limitations of unstructured individual or group decision-making (Ishizaka and Nemery 2013). Despite its comprehensiveness depicted by the various disciplines encompassed in **MCDA** and its variable applications, **MCDA** should not be considered a "wonder drug" to solving the decision making dilemma. The decision maker still has to make difficult judgments and no "right" answer results from the application of **MCDA.** Instead the main purpose of **MCDA** is to aid the decision making process.

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[15] Criteria are generally defined as standards for measurement or judgement (Olson 1996; Belton, and Stewart 2002.

The decision making task seeks to integrate objective measurement with value judgment while making explicit account of multiple criteria and managing subjectivity (Belton and Stewart 2002). Although various **MCDA** procedural representations exist, the methodology consists of at least 6 steps, which include; identification of problems, formulation of objectives, criteria and indicators, identification/formation of alternatives, description of performance for each alternative, weighting and evaluating scores of criteria for each alternative, examining results and conducting a sensitivity analysis.

MCDA is applied for sustainability assessment in this research since it enables the combination of various methods applied and the tool offers a platform through which a complex problem reflected by the scope considered with regards to integrated sanitation approach is structured. In so doing, the outcome from the sustainability assessment is expected to guide decision making with regards to integrated sanitation systems. Moreover, the results from the sustainability assessment are also expected to inform the development of a planning framework for the integrated sanitation system approach.

5.8 Development of a Planning Framework

This final stage of the research involves suggesting steps for a planning framework for the integrated sanitation system approach. Given that the approach suggested in this study is based on the environmental sanitation concept, reference is made to planning tools for existing environmental sanitation approaches considered for urban sanitation (EAWAG-SANDEC 2005; Lüthi et al. 2011a; NETSSAF 2006; Sawyer et al. 1998). Moreover, input from the various stages of the research i.e initiation phase, feasibility and sustainability assessments is also referred to further inform the development of the planning framework.

In conclusion, this chapter discusses the research methodology with reference to the research conceptual framework. Given that a case study approach is considered in this research, the case study selection criteria are discussed. Thereafter, an appreciation of the tools used during the research is carried out. Finally, a discussion of methods considered and those later selected to accomplish the tasks in the various phases of the research is accomplished. Using the various methods selected, the following chapters give detailed discussions of the various phases of the research with reference to **UCU** as a case study.

6 Assessment of Local Context: UCU as a Case Study

Chapter 6 *gives an overview of the initiation phase of the research with reference to the conceptual framework. An assessment of the local context of the case study area is carried out, identifying opportunities for sanitation improvements. Experimental analysis of substrates from **UCU** is also carried out to determine the viability of anaerobic digestion as a key process for the improved sanitation system for **UCU.***

6.1 Assessment of Local Context

As described in Chapters 1 and 4 of this dissertation**, UCU** is a private institution of higher education located in Mukono Municipality in Uganda. In this research, **UCU** was considered the case study area and key aspects to note about the University include;

- The challenge to finally dispose of at least 70% residual sewage sludge from the lagoons at the University`s **WWTP.**
- **UCU** also has a two stance pit latrine, implying that faecal sludge accumulated over a 2-3year period has to be further managed. The current mode of faecal sludge management consists of hiring a cess pool emptier to empty the latrine and deliver the faecal matter to designated locations. These locations include National Water and Sewerage Corporation faecal sludge management plants at Bugolobi or Lubigi in Kampala.
- Currently, kitchen waste mainly from the University dinning/kitchen is collected by interested farmers and used as animal feed. The kitchen waste is composed of food waste accounting for atleast 70% and peelings about 25%. A mutual understanding between the kitchen management and the farmers exists, where the farmers collect kitchen waste at no cost while offering a waste disposal service to the kitchen management.
- Plastics generated within the University are sorted and recycled by a private service provider. A fraction of solid waste generated from the University is also collected and transported to the landfill, which is located about 7km from **UCU** campus. While other solid waste is incinerated at **UCU.** Also, the University plans to install an additional incinerator for management of medical waste from the University clinic and medical department.
- **UCU** is heavily dependent on firewood for cooking. About 90% of cooking energy needs are covered by firewood utilisation. Based on such a background, the University management is interested substituting firewood use with cleaner energy sources such as biogas. In her 6 year strategic plan (2012-2018), **UCU** plans to ensure sustainable sanitation while additionally producing biogas from organic waste like sewage sludge.

6.2 UCU Surrounding

- **UCU** also owns a farm in Ntawo located about 3.5km from the University campus. The farm is currently leased to a private diary farmer who keeps Friesian cows.
- Mukono Municipality currently does not have a centralised **WWTP** nor is it connected to the National Water and Sewage Corporation (**NWSC**) sewer network. Moreover, onsite sanitary facilities which mainly include pour flush toilets connected to septic tanks and pit latrine are commonly used in the municipality. The use of these onsite facilities implies further management of sewage and faecal sludge is required. Figure 6-1 shows an overview of certain waste and wastewater management measures at **UCU.**

Stabilised sewage sludge from the lagoons collected in bags by interested farmers

Sorted plastic waste ready for transportation to recycling plant.

Incinerator used for burning other waste at **UCU**

Two stance pit latrine at **UCU**

Figure 6-1: Shows measures of waste and wastewater management at UCU
Source: Author

The information summarised about **UCU** and her surroundings illuminates the opportunity for improvement of the current sanitation system to cater for provisions for better treatment/management and disposal of the sewage sludge left in the lagoons. Moreover, the University is highly dependent on firewood for cooking and yet there is potential to generate renewable energy sources such as biogas from management of organic waste i.e. sewage sludge and other organic wastes and this further illuminates the opportunity for sanitation improvement. Management of sewage sludge can be achieved through various methods some of which include; aerobic or anaerobic digestion, co-composting, solar drying, thermal treatment, lime stabilisation (Healy et al. 2015).

As already highlighted in Chapter 3, anaerobic digestion process can be applied for management of sewage sludge and other organic waste streams(Monnet 2003; Al Seadi et al. 2008). The fact that the byproducts from anaerobic digestion of such organic waste streams include biogas and organic fertilizer makes consideration of the technology an attractive option for **UCU**. Moreover, by anaerobically digesting the sewage sludge and other organic waste streams generated at the University, management of organic waste can be achieved. As such, improved management of sewage sludge from the **WWTP** and the possibility to shift from dependence on firewood for cooking purposes to utilisation of clean sources such as biogas can be achieved for **UCU** incase anaerobic digestion is considered. Therefore, with reference to the potential benefits that can be accrued, preliminary consideration of anaerobic digestion technology as part of the improvement measures for sanitation at **UCU** was considered.

Based on the sanitation system value chain discussed in Chapter 3, baseline information obtained from **UCU** highlighted the opportunity for improvement in the treatment phase of sewage sludge. Thus, the current challenge of final disposal of sewage sludge would be catered for. Table 6-1 shows various technologies/processes for the respective value chain components of the **UCU** sanitation system.

Table 6-1: Technologies and Processes of the UCU Sanitation System Value Chain

Sanitation chain components	User interface	Storage/ containment	Conveyance	(Semi)-centralised treatment	Disposal/ reuse
Current system	Flush toilet		Simplified sewer	Activated sludge WWTP + lagoon	Partial application of sewage sludge on land by local farmers Continuous storage of excess sludge in lagoons
	Pit latrine	Pit latrine	Cess pool emptier	Faecal sludge plant	
Improvement				Biogas reactor Co-composting Co-incineration	Organic fertilizer/compost application Briquettes from digestate

Source: Author

6.3 Anaerobic Digestion (AD)

The **AD** process described in Chapter 3 is dependent on environmental conditions in particular, Methanogenesis which is also the last step of the anaerobic digestion process is severely influenced by operation conditions. As such, the composition of feedstock, feeding rate, temperature, and pH are examples of factors that influence the Methanogenesis process (Al Seadi et al. 2008; Angelidaki et al. 2009). Taking into consideration that application of the anaerobic digestion technology as a main component for improvement of the sanitation system at **UCU** is proposed**,** a detailed understanding of the process with reference to the **UCU** context was prudent. This would avoid the common mistakes made in assuming that since a technology has “worked”, even as part of a sustainable system elsewhere, it is appropriate (Andersson et al. 2016a; Lüthi et al. 2009)**.** Thus, the technical viability of **AD** for proposed sanitation system improvement at **UCU** was carried and this was informed by experimental analysis. Moreover, the decision to carry out experimental analysis was further influenced by the need to know the viability of organic wastes such as the sewage sludge from **UCU** as substrates or inputs for **AD**. To fully appreciate the findings from the experimental analysis, a brief description of key terms used follows;

6.3.1 Key Terms Used During Experimental Analysis

***Anaerobic degradability*;** is the degree of microbial decomposition of substrates or co-substrates and is generally expressed as biogas formation potential.

Biogas yield; is the quantity of biogas per quantity of substrate feed.

Digester: is the reactor in which digestion takes place

***Dry matter or Total Solids(TS)*;** is the content of substances which are left after thermal removal of water and this may include drying for 24 hours at 105 °C or drying until a constant weight is achieved

Hydraulic retention or residence time; is the average time for which the substrate remains in the digester.

Inhibition; basically means hindering of the anaerobic digestion process due to damage to the active micro-organisms or to a reduction in the effectiveness (activity) of enzymes.

Inoculum; also known as seeding sludge is the microbial biomass which is added at the beginning of anaerobic digestion process or during the course of the process to accelerate it.

Organic dry-weight content(oTS);is the weight lost with respect to the starting mass or starting volume of a sample which, following drying until a constant weight is reached, is reduced to ashes at a temperature of 550 °C.

Organic loading rate; is the ratio of the daily load to the digester volume.

Substrate; which is also referred to as feedstock, is the raw material for the anaerobic digestion process (VDI 2006; Al Seadi et al. 2008).

Prior to the experimental analysis, determination of available substrates was carried out. Thereafter, the experimental analysis involved characterisation of substrates, determination of respective biogas yields and process optimisation as discussed in following Sections.

6.4 Substrate Composition

Sewage sludge is considered a multi-substance mixture mainly because of the inhomogeneity and tremendous differences in the concentrations of its components. Often the case, it is difficult to determine or define a standard composition for sewage sludge since this may be influenced by the source of wastewater and treatment methods applied.

Nevertheless, sewage sludge is mainly composed of organic substances in addition to other substances such as heavy metals, pathogenic substances, proteins, nitrogen, phosphorus nutrients and toxic organics among others (Metcalf and Eddy 2004; Wiechmann et al. 2013).

Faecal sludge is raw or partially digested slurry or semisolid and results from the collection, storage or treatment of combinations of excreta and black water with or without grey water (Strande et al. 2014; Tilley et al. 2014). Faecal sludge is obtained from onsite sanitation technologies/facilities and has not been transported through a sewer. Examples of onsite technologies from which faecal sludge is obtained include pit latrines, unsewered public ablution blocks, septic tanks, aqua privies and dry toilets. The variety of onsite technologies from which feacal sludge is obtained make it difficult to determine faecal sludge characteristics as well (Strande et al. 2014).

Cow dung is basically made up of digested grass and grain. Cow dung is high in organic materials and rich in nutrients although exact composition is often dependent on the cattle feed.

Kitchen waste from **UCU** is composed of about 75% of food waste and about 25% peelings (bananas, potatoes etc.). The food waste consists of a mixture of carbohydrates, proteins, vitamins from the fruits and vegetables included in the daily diet.

6.5 Substrate Availability

Sewage sludge from **UCU WWTP** is one of the key substrates proposed for the **AD** process. Other available substrates included kitchen waste from the University kitchen, cow dung from the farm and faecal sludge was also considered. As noted, kitchen waste is currently freely given to interested local farmers who use it as animal feed. Preliminary consultation with kitchen administration indicated that alternate utilisation of the kitchen waste by the University is not expected to meet any resistance from the local farmers. The assertion is based on that fact a mutual agreement exists between both parties, where the farmers obtain the waste freely while helping **UCU** get rid of the kitchen waste.

Although currently dumped in the animal kraal or occasionally used by interested farmers as soil conditioner in nearby gardens, cow dung from the farm could also be a potential substrate for the **AD** process proposed for **UCU**. In obtaining cow dung from the dairy farmer, **UCU** would help the farmer get rid of unwanted dung in the kraal. Moreover, the fact that farm has been leased by **UCU** to the farmer implies both parties can benefit from an already existing relationship.

Mukono Municipality does not have a **WWTP** or faecal sludge treatment plant and yet mainly onsite sanitation systems are used. This poses a challenge for the Municipality and an opportunity for **UCU**. Faecal sludge from homes and other institutions which would otherwise be illegally dumped or transported to other treatment plants could be managed at the **WWTP** in **UCU,** which is currently operating at half its capacity.

UCU operates based on a three semester system, implying that out of 52 weeks in the year, the University is open for 45 weeks. As such, up to 87% availability of sewage sludge and kitchen waste substrates can be guaranteed. Cow dung availability is assumed to be all year round and the same applies for faecal sludge since availability would be influenced by demand for faecal sludge management within the Municipality. Table 6-2 shows a summary of available substrate quantities for the proposed **AD** process.

Table 6-2: Substrate quantities

Inputs/substrates	Estimates	Annual estimates
Sewage sludge	15m^3 /week	675m^3/year
Kitchen waste	1000kg/day	315 tones/year
Cow dung	770kg/day	277tones /year
Faecal sludge	333Kg/day	105tones /year

Source: Author

6.6 Experimental Analysis

The experimentation phase in this research was carried out over a duration of 3.5 months and it was based on a twofold objective; *evaluation of the biogas yield of organic waste streams (substrates) obtained from **UCU*** and *determination of ideal **AD** operation conditions*. To fulfill these objectives, characterisation of substrates was carried out followed by the bio methane potential (**BMP**) experiment and continuous stirred tank reactor experiment (**CSTR**).

BMP Experiment; is fundamental for evaluation of the possible biogas yield from any kind of substrate(s) or co-digestion of several substrates. The experiment also evaluates anaerobic biological degradability of single substrate(s) or mixtures (VDI 2006).

CSTR Experiment; is used to simulate real life conditions in a biogas reactor. Hence, the experiment gives guidance on anaerobic digestion optimisation. Since **AD** is dependent on environmental conditions, the process is highly complex and dynamic implying that process optimisation is important. Compared to other configurations like plug flow or sequencing batch reactors, the **CSTR** experiment is known to provide greater uniformity of system parameters i.e. temperature, mixing rate, chemical concentration and substrate concentration among others (Usack et al. 2012; Bioprocess 2014). The **CSTR** experiment was used to obtain time series data on gas yield, biogas composition in addition to understanding the **AD** course and process inhibition challenges for the substrates from **UCU.** The data obtained from the experiment simulated long-term process conditions in the digester, giving a comprehensive picture of the **AD** process and eventual guidance in case of implementation (VDI 2006; Usack et al. 2012).

6.6.1 Substrates Used

- **Activated Sludge (As)** from **UCU** was basically the waste activated sludge obtained after the secondary settler at the **WWTP.**
- **Old Sludge (Os)** was the waste activated sludge from the gravity settling tank at the University **WWTP. Os** was different from **As** since it was mainly waste activated sludge from the **WWTP** stored in $15m^3$ gravity settling tank for a duration of atleast one week. Once settled, the sludge would be dewatered, allowing for the more liquid portion to be returned to the **WWTP** while the more solid portion was directed to the lagoon for stabilisation. Thus, **Os** obtained and used for experimental analysis was the more solid portion of sewage sludge directed to the lagoons. Figure 6-2 shows the sewage sludge option (**As**) and **Os** used during experimentation.
- **Cow dung (Cd)** was from **UCU** farm located about 3.5km from main campus
- **Kitchen waste** consisted of food waste 75% and food peelings 25%. For experimentation purposes, only food waste (**Fw**) was utilised due to the simplicity associated with sample preparation in the laboratory. Tube clogging even after size reduction of peelings using a cutter deterred their use during experimentation.

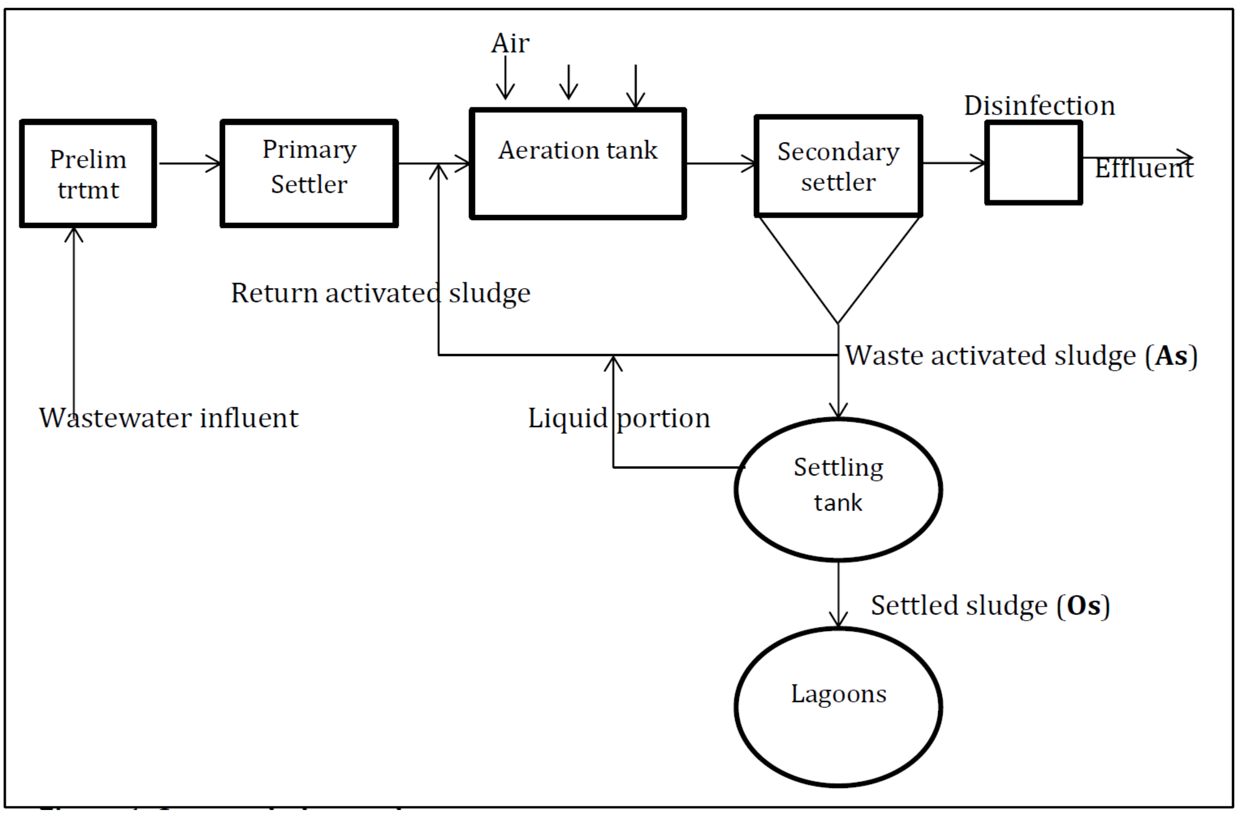

Figure 6-2: Sewage sludge used
Source: Author

6.6.2 Other Substrates Used

Experimentation was carried out at Flensburg University of Applied Science (**FAUS**) mainly due to the availability of necessary laboratory equipment. As such, substrate samples were collected from **UCU** and transported to Flensburg, Germany. However, due to international restrictions related with delivery of samples such as sewage sludge, food waste, cow dung, continuous supply of the substrates from the **UCU** was often delayed. In the absence of substrates from **UCU**, samples considered quite similar were obtained from within Germany.

Specifically, waste activated sludge (**As)** and cow dung **(Cd)** was obtained from Nordstrand, a peninsula located on the North Sea about 58km from Flensburg. This location was chosen because wastewater treatment at Nordstrand was also achieved using an activated sludge **WWTP**. In addition, the main source of the wastewater treated at Nordstrand **WWTP** was mainly from households in the area. These conditions were considered quite representative to the **UCU** scenario where wastewater sources were mainly halls of residence, lecture rooms and offices.

Noteworthy is that for all samples transported either from Uganda or within Germany, proper sample storage conditions were carried out to ensure that they were representative for experimentation. Moreover, prior to consideration of **As** from Nordstrand **WWTP**, other smaller **WWTPs** within the outskirts of Flensburg city were visited. Although some of the **WWTPs** served mainly residential and small farm communities, the technology used in the respective treatment plants was based on sequencing batch reactors, which have a slightly different operation principle in comparison to the activated sludge wastewater treatment. Cow dung (**Cd**) was also obtained from a farm at Nordstrand and used only in the absence of **Cd** from **UCU**, allowing for continuity of the experimentation processes.

6.7 Characterisation of Samples

Prior to carrying out both **BMP and CSTR** experiments, characterisation of the samples was required. Determination of the total solid (**TS**) and organic total solids or volatile solid (**VS/oTS**) content for each of the substrates and inoculum was necessary since computation of sample amounts for **BMP** and **CSTR** experiments was dependent on **TS** and **oTS.** Characterisation of samples was carried out using various analytical methods discussed.

Total solids (TS) for the respective substrates was examined according to **EPA 1684** method for determining total, fixed, and volatile solids in water, solids, and bio-solids. Moreover, reference to similar experimentation guidelines i.e. **VDI 4630** guidelines was carried out to inform characterisation of samples (EPA 2001; VDI 2006).

Sample characterisation methodology; a triplicate of samples was dried at **T=105 °C** for 24 hours until constant weight was reached.

Thus, components within the samples consisting of lower boiling points such as alcohols and volatile fatty acids (**VFA**) evaporate at this phase. **TS** for respective samples were calculated with reference to Equation 6-1.

$$\textbf{Total Solids (TS)} = \frac{\textbf{Mass of dry sample (g)}}{\textbf{Mass of fresh sample (g)}} \quad \text{.......................................Equation 6-1}$$

Organic total or volatile solids (oTS) assumed to be the organic part of the sample was equally examined with reference to **EPA 1684** method. Here, the dried samples were burned at **T=550 °C** until constant weight was reached. **oTS** for the respective samples was calculated according to Equation 6-2.

$$\textbf{Organic total solids (oTS)} = 1 - \frac{\textbf{Mass of ash (g)}}{\textbf{Mass of dry sample (g)}} \quad \text{...............................Equation 6-2}$$

Furthermore, substrate **pH-**measurements were carried out using a **WTW** Sentix pH meter.

6.7.1 Experimental Design.

Currently, there is no standard **BMP** protocol mainly because the process of anaerobic degradation is a highly complex and is a dynamic system where microbiological, biochemical and physio-chemical aspects are closely linked (Angelidaki et al. 2009). Hence, modification of key aspects discussed in various **BMP** protocols was considered and the most important modification included degassing of the inoculum[16].

Sewage sludge obtained from Flensburg **WWTP** was used as inoculum. The inoculum was left in a closed plastic container over a duration of one week to degas under test temperature conditions prior to utilisation in both the **BMP** and **CSTR** experiments. Degassing of the inoculum was carried out in order to deplete the residual biodegradable organic material present in the inoculum by means of a hunger phase (VDI 2006). Other **BMP** protocols suggest purging of inoculum/substrate mixture with nitrogen or nitrogen oxygen mixture or incubation for 2-5days prior to setting up the experiment (Angelidaki et al. 2009; VDI 2006). The **CSTR** experiment was carried out with reference mainly to **VDI 4630** guidelines (VDI 2006).

6.7.2 BMP Experimental Setup

The **BMP** experiment was setup based on the Mariotte displacement principle for quantifying methane produced as shown in Figure 6-3. The setup consisted of eleven 500ml glass *Duran* bottles referred to as reactors which were placed in a water bath and the water in the bath was maintained at constant temperature of 39°C.

Prior to placing reactors in the water bath, duplicate samples of **Cd**, **As**, **Os** and **Fw,** each mixed with inoculum and two "blanks" or control reactors containing only inoculum were placed in ten reactors. The eleventh reactor also known as the reference sample consisted of a mixture of inoculum and corn starch used to check the biological activity of the inoculum (VDI 2006). To standardise the course of digestion, 300ml of inoculum was placed in each of the 500ml reactor bottles before addition of substrate. Addition of 100ml of **As** and **Os** to the inoculum was carried due to the low **oTS** values of the substrates (Healy et al. 2015). While **Fw** and **Cd** amounts were estimated with reference to Equation 6-3.

$$\frac{\textbf{oTS substrate}}{\textbf{oTS seeding sludge}} \leq \textbf{0.5} \quad \text{......Equation 6-3}$$

After placing the sample-inoculum mixtures in the reactor bottles, the reactors were positioned in the water bath. Connections from the reactors were then made to 500ml *Duran* bottles containing 500ml alkaline or scrubbing solution. The scrubbing solution was a mixture of 20g of sodium hydroxide in 1 liter of water and had a pH of 13. From the scrubbing solution bottles, connections were made to 500ml displacement bottles containing water colored with methyl orange indicator. The purpose of the colored water was to simplify reading of displaced water volumes against the glass cylinders. The produced biogas from the reactor bottles was passed through the scrubbing solution where the CO_2 was retained. Thus, the displaced methyl orange colored water collected in the 250ml *Duran* glass cylinders was equivalent to $\mathbf{CH_4}$ produced and was measured on a daily basis. During the initial stages of the experiment, gas volumes were measured twice a day however as the experiment progressed, measurement was carried out once daily. Reactor bottles in the water bath were shaken once daily after displaced water readings were taken. The experiment was run for 30 days thereafter, a similar experimental setup was used to analyse methane yields for substrate combinations;

- **CF** (**Cd:Fw 70:30)**,
- **X1(Os: Cd: Fw20:30:50)**,
- **FAC (As:Cd:Fw 20:50:30)**
- **FOC (Os: Cd:Fw 20:50:30).**

Figure 6-3 shows setup for the **BMP** experiment based on Mariotte displacement principle. while Figure 6-4 shows the actual **BMP** setup at **FUAS** laboratory.

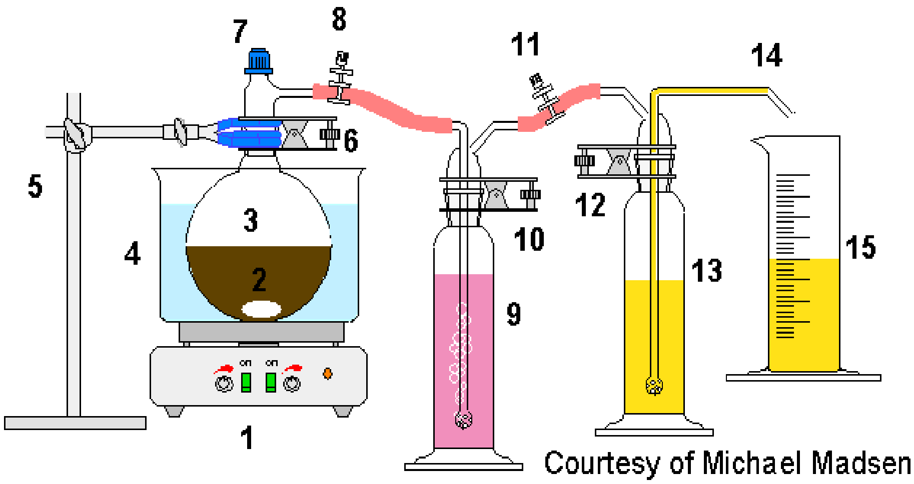

Figure 6-3: BMP setup according to Mariotte displacement method
Source: (Madsen 2006)

Where; 1 heat source, 2 magnetic stirrer, 4 water bath, 9 alkaline solution, 13 coloured water, 15 volume of methane.

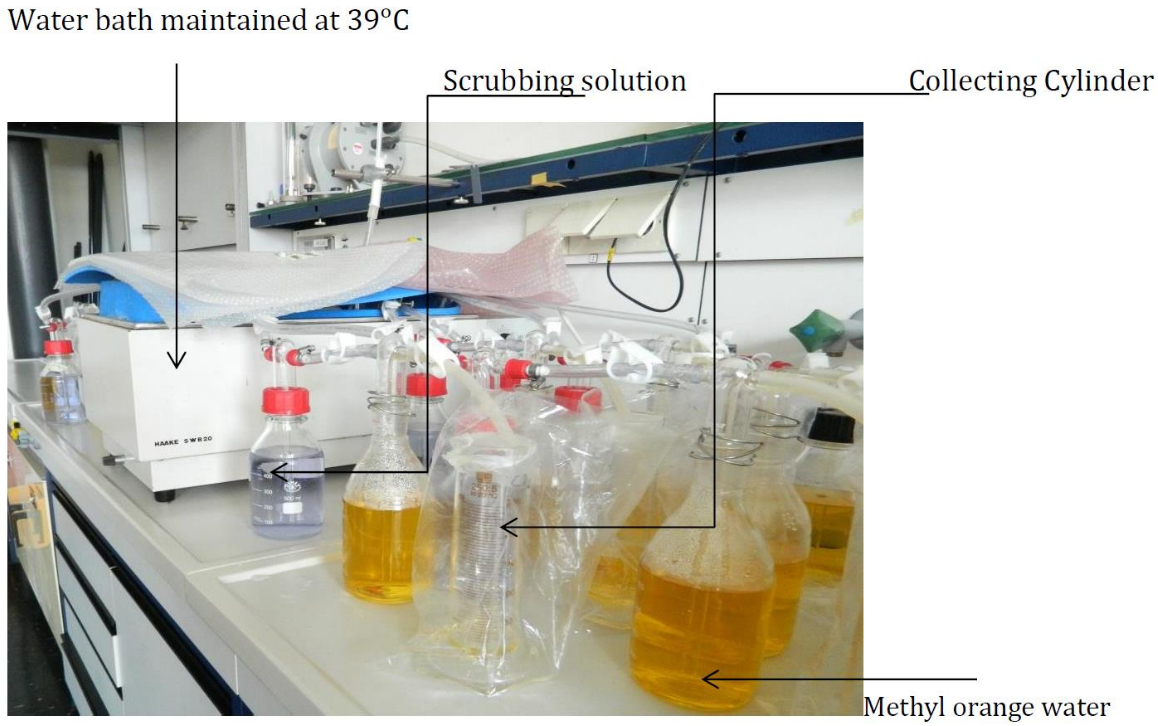

Figure 6-4: BMP setup for UCU substrates at FAUS laboratory
Source: Author

6.7.3 CSTR Experimental Setup

Three laboratory scale digesters referred to as **D1, D2** and **D3** each with a total volume of 4liters and a fourth 7 liter **INFORS HT** digester referred to as **D4** were used for the **CSTR** experiment. All four digesters were made of glass and were double jacketed. Already degassed inoculum was placed in the digesters prior to sealing them with head plates which had provisions for magnetically run **Janke & Kunkel** stirrers. Moreover, the head plates also had provisions for substrate feeding, digestate outlet and gas outlet respectively.

For **D1**, **D2** and **D3,** substrate feeding and digestate abstraction was generally carried out automatically while manual feeding was carried out for **D4**. Manual feeding of substrate was carried out for **D4** due to its design and the digestate was forced out with the help of suction mechanism. At the initial stages of the experiment, substrate feeding and digestate abstraction for **D1, D2** and **D3** was carried out automatically with the help of timers and additional pumps. However, in the later stages of the experiment, plugging of the tubes especially during substrate feeding became a limiting factor resulting in manual feeding for **D2** and **D3.** Despite manual feeding of **D2** and **D3** in latter stages of the experiment, potential of gas leakage in all digesters was checked by ensuring all inlets and outlets were sealed off using clamps when not in use. Furthermore, a condensate and foam trap was included for each of the digesters to prevent any gas leakage in case of filled up gas bags (Cali-5-Bond).

Daily operations for the **CSTR** experiment included;

1. Removal/replacement of gas bags
2. Removal of expected digestate amount and pH was measured before disposal and further sampling.
3. Feeding of substrate mixture (**D1, D2** and **D3**)
4. For **D4,** a portion of digestate abstracted used for mixing substrate prior to feeding (digestate recycling).
5. Lastly, sampling of gas to determine composition was carried out

Figure 6-5 shows the **CSTR** experimental setup at **FAUS** laboratory.

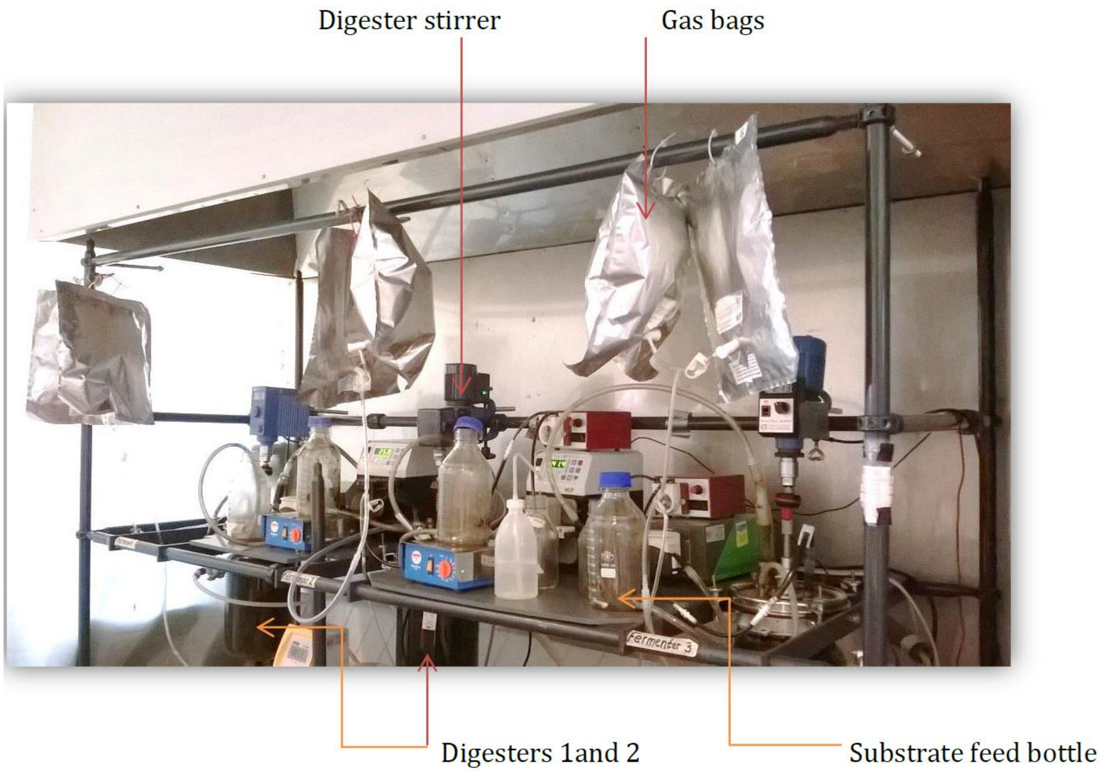

Figure 6-5: CSTR experimental setup for digesters 1, 2 and 3
Source: Author

6.7.4 Sampling Methods

Measurement of substrate quantities fed in to digesters was based on increasing organic loading rate (OLR Kg oTS/m³.d). The substrate and digestate quantities were calculated with reference to Equation 6-4.

$$m_{feed} = \frac{OLR*Vr}{TS_{feed}*oTS_{feed}} \quad \text{.....................Equation 6-4}$$

Where; m_{feed} is quantity of feed in grams, **OLR** is organic loading rate, V_r is digester volume.

6.7.4.1 Digester Stability

An amount of digestate equal to the substrate fed was abstracted from the respective digesters. On a daily basis, the pH of the digestate was checked while the volatile fatty acid (VFA)/Total Inorganic Carbon (TIC) ratio - **VFA/TIC** of the digestate from all digesters was measured weekly. **VFA/TIC** ratio is an important indicator for anaerobic digester stability.
Reference to the **VFA/TIC** digester stability ranges summarised in Table 6-3 informed experimental analysis discussed further in the results section.

The **VFA/TIC** value was determined by titration using the Nordmann method (NORDMANN 1977). Digestate samples were titrated with 0.1N sulfuric acid from initial pH to pH=5.0, determining the carbonate buffer capacity. Afterwards, titration was continued to pH=4.4, to determine the buffer capacity of volatile fatty acids, which have a pK *s* in the range of 4.6 to 4.9 (NORDMANN 1977; Drosg 2013). The **VFA/TIC** value can be calculated using Equation 6-5.

$$\mathbf{VFA/TIC} = \frac{\left((V_{pH\,4.4} - V_{pH5.0}) * \frac{20}{V_{sample}} * 1.66 - 0.15\right) * 500 * V_{sample}}{0.05 * V_{pH\,5.0} * M_{CaCo3} * 1000} \quad \text{……………….Equation 6-5}$$

Where; V_{sample}- sample volume [ml], VpH 5.0- volume of added acid until pH 5.0 is reached [ml], VpH 4.4- volume of added acid until pH 4.4 is reached [ml], M_{CaCO3} - molar mass of calcium carbonate. Titration is conducted with a Metrohm 736 GP Titrino. The uncertainty of measurement is estimated from repeated titrations to be $uV\ FA/TIC$ = ±0.03.

Table 6-3: Controlling anaerobic digestion by checking process stability

VFA/TIC value	Reason	Action
>0.6	Digester strongly overfed	Stop feeding
0.5-0.6	Digester overfed	Decrease feeding
0.4-0.5	Digester strongly loaded	Increase observation
0.3-0.4	Digester optimally loaded	Hold feeding
0.2-0.3	Digester underfed	Increase feeding
<0.2	Digester strongly underfed	Accelerate feeding

Source: (Lossie, and Pütz 2008)

6.7.4.2 Gas Analysis

Produced biogas collected in gas bags was quantified by measurement of the duration required to empty the gas bags when connected to the gas analyser. The analyser consisted of an inbuilt pump mechanism which sucked in the gas at a constant flow rate of 600 ml/min while additionally analysing gas composition. The **VISIT 03 Messtechnik Eheim** gas analyser measured methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) hydrogen (H_2) and hydrogen sulphide (H_2S) composition in biogas although, the main focus was on $\mathbf{CH_4}$ and $\mathbf{CO_2}$ amounts. Uncertainty in measurement was catered for based on the measurement information for the gas analyser summarised in Table 6-4

Table 6-4: Gas measurement & uncertainty

Parameter	Range	Uncertainty
Gas volume	infinite	±4% rel.
CH_4	0 ÷ 80 vol-%	±1 vol-%
CO_2	0 ÷ 60 vol-%	±1 vol-%
H_2	0 ÷ 10, 000 ppm	±100 ppm
O_2	0 ÷ 25 vol-%	±1 vol-%

Source: (Stefan 2014)

6.7.5 Digester Operation

For each of the digesters, different substrate compositions were fed and after a constant hydraulic retention time (HTR) of 14 days was maintained, the substrate composition and **OLR** were changed. Variation of the **OLR** was carried out with reference to (VDI 2006) protocol which suggests that **OLR** can be increased after every 14 days until specific gas production no longer increases (VDI 2006). **D1, D2** and **D3** were operated continuously for 88, 79, 76 days respectively while **D4** was only operated for 44 days. The variation in operation duration was attributed to the different digester startup times. Table 6-5 gives an overview of respective digester process conditions.

Table 6-5: Overview of Respective Digester Process Conditions

Digester	Feed composition	Duration (Days)	OLR KgoTS/(m^3*d)
D1	As:Cd:Fw 33.3: 33.3:33.3	0-14 15-29	0.5 1
	As:Cd:Fw 20:50:30	30-44	1.5
	As:Cd:Fw 20:30:50	45-57	1
	As:Cd:Fw 10:45:45	58-72 73-88	1.5 2
D2	O:Cd:Fw 50:20:30	0-14 15-29	1 1.5
	Cd: Fw 40:60	30-43	2
	Cd:Fw 70:30	44-57	2
	O:Cd:Fw 50:20:30	58-67	2
	As:Cd:Fw 10:45:45	68-79	2.5
D3	O:Cd:Fw 33.3:33.3:33.3	0-14 15-29	1 1.5
	Cd:Fw 50:50	30-43	2
	Cd:Fw 30:70	44-57	2
	O:Cd:Fw 33.3:33.3:33.3	58-67	2
	As:Cd:Fw 40:30:30	68-76	2.5
D4	Cd:Fw 70:30	0-17 18-31 32-44	1 1.3 2.5

Source: Author

As already noted, measurement of anaerobic digester stability reflected by the **VFA/TIC** ratio for digestate abstracted informed the adjustment of **OLR** of substrates fed into the digesters and is discussed further in Section 6.8.

6.8 Experiment Results

Discussion of results is organised in three steps i.e. characterisation of substrates, **BMP, CSTR** experiments.

6.8.1 Characterisation of Samples

Prior to use in both **BMP** and **CSTR** experiments, samples were characterised thus, determination of the **TS (%)** and **oTS (%)** of substrate samples from both **UCU** and Nordstrand, Germany was carried out and results are summarised in Table 6-6.

Table 6-6: Summary of Substrate and Inoculum Characterisation

No	Substrate	TS (%)	oTS (%)
1	**As** from **UCU**	0.66-1.07	81.89-81.37
2	**Os** from **UCU**	1.42-2.94	71.22-72.81
3	**Cd** from **UCU**	13.20-17.33	76.67-76.53
4	**Fw** from **UCU**	22.56-26.55	96.21-97.20
5	**As** from **Nordstrand, Germany**	0.3-0.53	76.22-66.45
6	**Cd** from **Nordstrand Germany**	13.02	85.69
7	Sewage sludge from Flensburg **WWTP**(inoculum)		58.83%

Source: Author

Respective **TS** and **oTS** values were used to compute amounts of samples used for the **BMP** and **CSTR** experiments with reference to Equations 6-1 and 6-2 respectively.

6.8.2 BMP Experiment Results

The initial **BMP** experiment considered samples **As, Fw, Cd**, **Os,** inoculum and corn starch. For each of the samples, CH_4 yield was measured and Figure 6-6 shows the respective CH_4 yields for the samples.

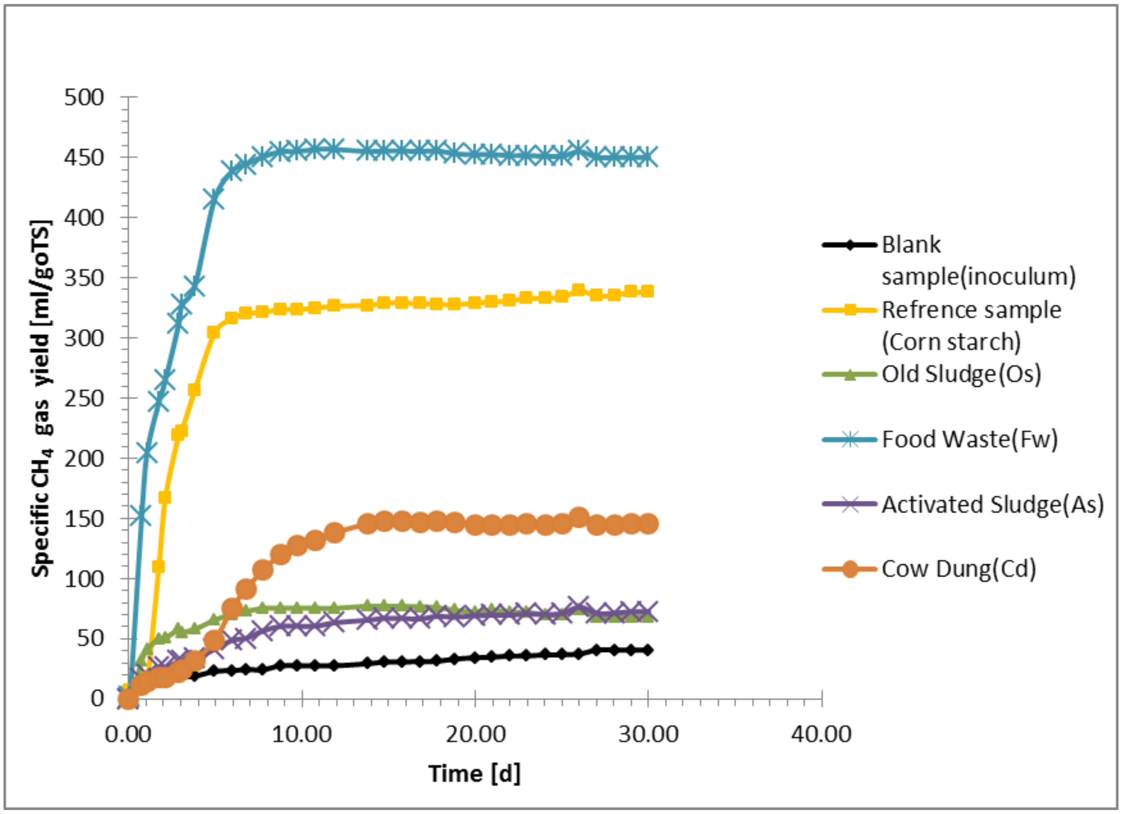

Figure 6-6: oTS CH_4 yield for samples from UCU
Source: Author

As shown in Figure 6-6, the **BMP** results indicated that **Fw** had the highest **CH_4** yield followed by **Cd,** then **Os** until about the 21st day before an equal **CH_4** yield was observed for both **Os** and **As.** The findings concur with other findings in literature which also show that anaerobic digestion of **Fw** in comparison to other substrates such as **Cd** and sewage sludge results in higher biogas yield (Al Seadi et al. 2008; Vögeli et al. 2014). Overall, **Fw** digestion registered **CH_4** of at least **450 ml/goTs**, **Cd** yield **147 ml/goTS** while **Os and As** yielded atleast **73 ml/goTs** of **CH_4.**

The delayed degradation of **Cd** shown in the first 3 days of the experiment was associated with the slow hydrolysis stage which is the initial stage of anaerobic digestion process. Particularly with reference to **Cd** which is composed of lignocellulosic materials in grass remains, literature suggests that hydrolysis stage is delayed due to the hindrance to the rate of biodegradation of the lignocellulosic material (Khalid et al. 2011)**.** Degradability is however improved after the hydrolysis stage which is also considered the rate limiting stage. At the initial stages of the experiment, faster degradation of **Os** in comparison to **As** shown by the respective curves was attributed to the fact that **Os** was partially stabilised while **As** was not stabilised as all.

As described in Section 6.61**, Os** consisted of waste activated sludge **(As)** left in a settling tank for atleast a week where the sludge was dewatered prior to further stabilisation in the lagoon. Through the process of settling and dewatering **As** in the settling tank, partial stabilisation occurs resulting in a more degradable **Os.** The delayed initial biodegradability of **As** during the hydrolysis stage shown by the curve was attributed to lower availability of anaerobic biomass in **As** compared to **Os.** After undergoing a highly aerated process in the **WWTP, As** is considered to have has less biodegradable biomass compared to **Os** which was dewatered after settling in gravity tank. These findings concur with those of (Carrere et al. 2008) who determined that sludge originating from an extended aeration process was less biodegradable than sludge from a high-load process. Also, low biodegradability of **As** at the hydrolysis stage which is the rate limiting stage for anaerobic digestion of sewage sludge, was attributed to the composition of sewage sludge(Appels et al. 2008).

Generally, sewage sludge is rich in proteins and thus, a lower hydrolytic potential than carbohydrates and lipids is expected during anaerobic digestion (Mottet et al. 2010; Iacovidou et al. 2012). The increased biodegradability of **Os** in comparison to **As** at the initial stages of the experiment was attributed to the fact that settling and dewatering of sludge in the gravity tank which acted as a pretreatment step, resulted in increased anaerobic biomass for **Os.**

The second **BMP** experiment considered co-digestion of samples mixed with inoculum. A similar setup to the first **BMP** experiment was used and the substrate samples included;

- **CF (Cd:Fw 70:30)**
- **X1 (Os:Cd:Fw 20:30:50)**
- **FAC (As:Cd:Fw 20:50:30)**
- **FOC (Os:Cd:Fw 20:50:30)**

Figure 6-7 shows the findings from the 2nd **BMP** experiment.

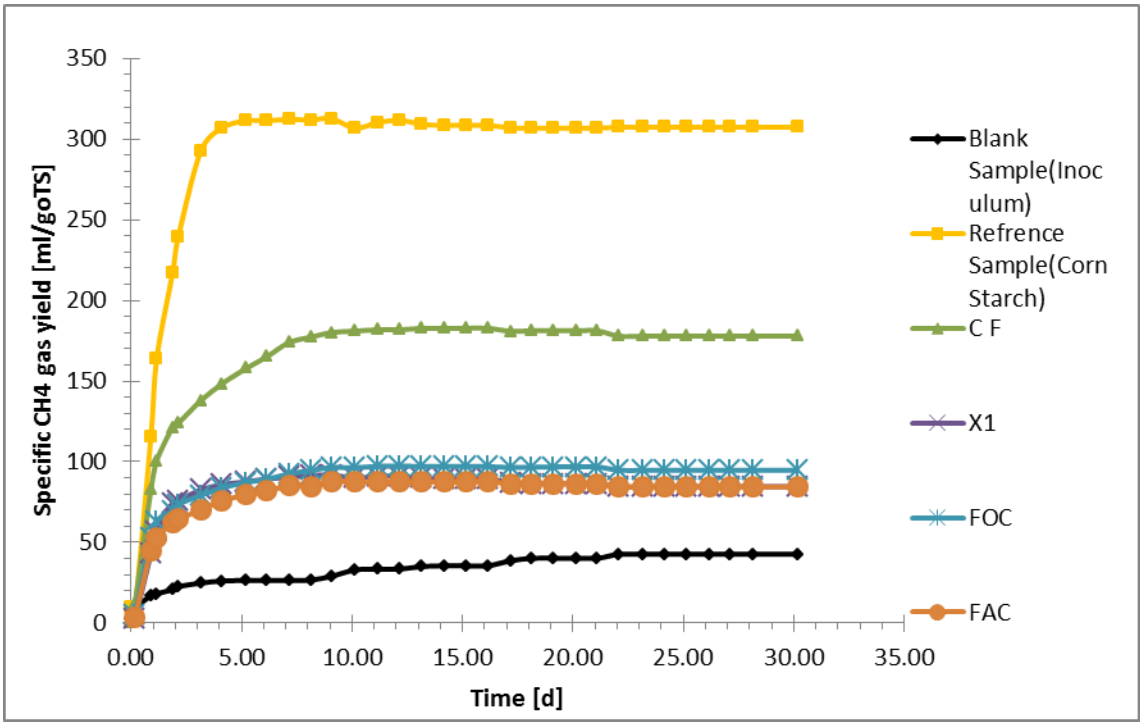

Figure 6-7: BMP for co-digestion of substrates from UCU
Source; Author

As shown in Figure 6-7, CH_4 yield from **CF** sample was the highest followed by **FOC, X1** and **FAC** with **183, 97, 88** and **88 ml/goTs** respectively. A notable distinction in the curves showed that none of the samples registered slow degradation at initial stages as was the case with the initial **BMP** experiment. The notable change showed all samples were easily degradable and this was attributed to co-digestion which is recommended as a measure for improvement of digestion efficiency of substrates (Khalid et al. 2011).

In comparison to **Cd** and **As** curves in the initial **BMP** experiment, curves **CF** and **FAC** showed improvement in degradability for **Cd** and **As** at the initial stages due to co-digestion with **Fw** and **Cd** respectively. Also, increased CH_4 gas yield for **X1** and **FAC** of **88 ml/goTs** in comparison to **73 ml/goTs** for **Os** and **As** respectively was registered and attributed to co-digestion respective samples. In line with these results, (Khalid et al. 2011) also found that co-digestion improves digestion efficiency of substrates.

Furthermore, increased CH_4 produced for the various samples could be attributed to co-digestion with **Fw.** Characterised by a high **C:N** ratio, addition of **Fw** improved the low **C:N** ratio of sewage sludge resulting in increased CH_4**.** Mottet et al. (2010) and Vögeli et al. (2014) obtained similar results when co-digestion of sewage and **Cd** with **Fw** was considered.

Therefore, the findings suggest that co-digestion of **As** and **Cd** with easily degradable **Fw** could have contributed to the acceleration of the hydrolysis stage, improving the overall performance of **Cd** and **As** shown by curves **CF** and **FAC.**

6.8.3 CSTR Experiment Results

For all four digesters, substrate mixtures were fed in to respective digesters and the digestate abstracted was checked for **VFA/TIC** ratio with reference to value ranges in Table 6-7. Necessary adjustments to substrate composition and **OLR** were based on **VFA/TIC** values measured, availability of substrate, digestate pH and analysis biogas composition. Table 6-7 gives an overview of the digester conditions and necessary adjustments considered.

Table 6-7: Summary of digester conditions and adjustments

Digesters	**OLR KgoTS/(m³*d)**	**VFA/TIC**	**Comment**	**Biogas composition** CH_4	CO_2
D1 **As:Cd:Fw 33.3: 33.3:33.3**	1	0.48	Digester strongly loaded	50.5%	41.5
As:Cd:Fw 10:45:45	2	0.31	Digester reached optimal conditions		
D2 **O:Cd:Fw 50:20:30**	1.5	0.21	Digester was underfed	53%	48%
	2	0.59	Digester was overfed, implying reduction in **OLR** KgoTS/ (m^3*d) would result in optimal conditions.		
D3 **O:Cd:Fw 33.3:33.3:33.3**	2	0.25	The digester was underfed thus, an increment in **OLR** to 2.5 KgoTS/(m^3*d) could be achieved	54%	51%
As:Cd:Fw 40:30:30	2.5	0.48	Digester strongly loaded thus, either reduction of **OLR** or reduction in **As** composition in substrate mixture could be considered.		
D4 **Cd:Fw 70:30**	2.5	0.4	Digester optimally loaded.	49%	45%

Source: Author

Results for the **CSTR** experiment summarised in Table 6-7 indicated that in case a substrate feed consisting of **As** was considered**,** then the most optimal composition was **As:Cd:Fw 10:45.45,** at an **OLR of 2.5 KgoTS/(m^3*d).** While for a mixture consisting **Os:Cd:Fw**, the composition **Os:Cd:Fw 33.3:33.3:33.3** showed that the digester was underfed at an **OLR** of **2 KgoTS/ (m^3*d).** Alternately, substrate composition of **O:Cd:Fw 50:20:30** at the same **OLR** indicated that the digester was overfed. Digester overfeeding was attributed to the increased amount of **Os** in the substrate which also influenced the pH of digestate, increasing it from 7.0 to 7.2. The composition of **Os** characterised by high protein content in comparison to carbohydrate and lipids, contributed to final variation in pH value (Mottet et al. 2010). As such, flexibility in adjusting **Cd** and **Fw** composition while maintaining **Os** at 30% could be considered.

Based on the findings discussed, compositions of **Os:Cd:Fw 30:30:40** or **Os:Cd:Fw 30:20:50** could be considered due to the ease with which **Fw** and **Cd** (after hydrolysis stage) degrade. For the proposed substrate compositions, modifications of **OLR** between **2** and **2.5 KgoTS/(m^3*d**) could be considered. The suggested composition options are not without justification since Maranon et al (2012) also determined that increment in **Cd** or **Fw** resulted in more stable digester conditions and higher **OLR.** Notwithstanding the variation in experimental setup and design, findings by Maranon et al (2012) using similar substrates suggests that possible increment of **Cd** or **Fw** at higher **OLR** can be achieved and could result in significant biogas yield while additionally offering optimal digester conditions**.**

For **D3,** substrate mixture with **Cd:Fw 70:30** showed optimal digester conditions at an **OLR 2.5 KgoTS/(m^3*d).** Also at an **OLR 2 KgoTS/ (m^3*d),** digestion of **Cd:Fw 30:70, 50:50** showed the digesters were underfed at VFA/TIC of 0.21. This implied that at **OLR 2.5 KgoTS/ (m^3*d),** the same mixture would probably yield biogas at optimal digester conditions**.** In line with these results, Zhang et al. (2013) found that for **Fw** :**Cd** at composition ratio **2:1,** high biogas yields and stable digester conditions resulted. Also, using similar substrates El-Mashad and Zhang (2010) showed that variable **Cd:Fw** compositions of **68:32** and **52:48** could be optimally used. Bearing in mind the variations that may be considered during experimental setup and design, the wide range of **Fw:Cd** considered applicable reflect the flexibility that can be adapted to substrate mixtures. Such flexibility would cater for scenarios of limited substrate availability, especially for **Fw** during semester breaks at **UCU**.

Analysis of biogas composition for all digesters showed percentage contribution of **CH_4** ranged between **49-54%** while **CO_2** ranged between **42-51%.** At such composition ranges biogas produced could be used as cooking fuel although scrubbing is recommended. During scrubbing, the biogas undergoes condensation, particulate removal, compression, cooling and drying thereby reducing impurities such as water vapor, other particles and hydrogen sulphide (H_2S) gas. H_2S gas is reported to have a corrosive effect to metal parts and also quickly corrodes non-ferrous metals in components, such as pressure regulators, gas meters, valves and mountings.

As such, the service life of key components such as gas burners, valves, mounting and even engines could be reduced. Particularly with regards to engines, the combustion process also produces sulphurdioxide (SO_2) which combines with water vapour forming an acid. The sulphuric acid formed badly corrodes engine parts and thus, the service life of the engine to the first general overhaul could reduce by about 10-15%. Therefore, the scrubbed biogas can then be efficiently utilised in burners and combined heat and power(CHP) units in case generation of electricity is considered (Al Seadi et al. 2008; Zhao et al. 2010). Further discussion of biogas yields from respective digesters is included in the Appendix 3.

In summary, the **BMP** experimental analysis showed that **Fw** was the most easily biodegradable substrate yielding the highest amount of **CH_4** followed by **Cd, Os** and **As** respectively. Also, co-digestion of substrates improved biodegradability, especially for **Cd** and **As** shown by curves **CF** and **FAC** in comparison to **Cd** and **As** curves**.** Moreover, increased **CH_4** yield was recorded during co-digestion of substrates i.e. **97, 88 ml/goTs** for **FOC (Os:Cd:Fw 20:50:30), X1(Os:Cd:Fw 20:30:50)** and **FAC** in comparison to **73 ml/goTs** for **Os** and **As** respectively.

Results from **CSTR** experimental analysis showed that a level of flexibility exists with regards to adjusting the supply/quantity of **Cd and Fw** while maintaining **Os** at 30%, resulting in increased biogas yields and optimal digester conditions. Thus, substrate compositions of **Cd:Fw 70:30, 50:50, 30:70** and **Os:Cd:Fw 30:20:50** or **30:30:40** could be considered.

In the event that sewage sludge directly from the **WWTP** was anaerobically digested, then substrate composition with much less sewage sludge was recommended i.e. **As:Cd:Fw 10:45:45.** The results also concurred with the discourse that pretreatment of sewage sludge boosted anaerobic digestion process (Appels et al. 2008; Karthikeyan, and Visvanathan 2013). The improved performance of **Os** in comparison to **As** in the various substrate compositions confirmed the influence of pretreatment on anaerobic digestion of sewage sludge**.** Moreover**,** at an **OLR** of **2-2.5 KgoTS/ (m^3*d)** optimal digester conditions for the various substrate compositions were obtained. As such, a minimum **OLR** of **2 KgoTS/ (m^3*d)** is recommended as suggested by Vögeli et al. (2014). The results from experimental analysis suggest that the organic waste samples/substrates from **UCU** are viable with regards to anaerobic digestion. Therefore, the preliminary assumption that anaerobic digestion technology could be considered a key process in management of organic waste streams from **UCU** was affirmed

In the event that **AD** is considered as key process for integrated sanitation systems which are meant to serve other domains such as housing estates, hospitals, towns and cities already highlighted in Chapter 3, then the first step would be to guarantee substrate availability. Once the availability of substrates is guaranteed, co-digestion of substrates should be considered. This is because the co-digestion of substrates not only allows for increased biogas yield but also contributes to process stability (Al Seadi et al. 2008; El-Mashad and Zhang 2010).

The compositions of substrate mixtures considered for co-digestion may vary based on the overall goal of applying the **AD** process. If for instance the goal is increased biogas yield, then consideration of more of the biodegradable substrates may be given priority. While if management of certain waste streams is priority albeit having low degradability or biogas yield, then the substrate mixtures for co-digestion may vary in favor of management of the organic waste stream.

However, a mixture of substrates, which includes those that are highly biodegradable such as food or bio waste with those that are considered less biodegradable at certain stages of the **AD** process such as cow dung would generally boost the **AD** process. Moreover, the pre-treatment of substrates is also crucial to boosting the **AD** process. Improvement of the **AD** process in terms of increased methane yield and solids reduction are some of the well-established advantages of pre-treatments. Depending of the substrates considered i.e mixed organic waste, faecal or sewage sludge from various locations, different pre-treatment measures may be employed. Sorting and cutting or size reduction of comingled organic waste or biowaste could be considered a pre-treatment measure. Particle-size reduction is considered to increase substrate surface area and this could increase biodegradability due to the exposure of biodegradable matter previously unavailable to microorganisms. Such pre-treatment measures could also boost solubilisation of the substrates (Carlsson et al. 2012; Al Seadi et al. 2008). While dewatering of sewage sludge or sorting and removal of unwanted material such as sanitary pads from faecal sludge could also be considered pre-treatment measures contributing to a better **AD** process.

Generally, it should be noted that in the event that experimental analysis for substrates or organic waste streams from various sources is not feasible, reference to available literature can inform necessary computations to determine biogas yield from potential substrates.

In conclusion, this chapter highlights the key points from the assessment of the local contexts at **UCU** and her surroundings. Thus, key "stressed" areas with respect to sanitation and possible opportunities for sanitation improvement are identified. Using experimental analysis of organic waste streams from **UCU**, additional information regarding the viability of **AD** process as a key component for the improved sanitation systems proposed in this research is obtained. As such, the combination of information related to demand for improved sanitation communicated by stakeholders as well as the assessment of the local context informs the design of integrated sanitation system alternatives discussed in Chapter 7 of this dissertation.

7 Design and Technical Feasibility Assessment of Sanitation System Alternatives Proposed for UCU

Chapter 7 *discusses the design of integrated sanitation system alternatives proposed for* ***UCU.*** *Informed by principles of sanitation service delivery and factors influencing sanitation system design, six sanitation system alternatives were designed. The second part of this Chapter includes the technical feasibility assessment of the six sanitation system alternatives. Finally, the Chapter concludes without a Strengths, Weaknesses, Opportunities and Threats (****SWOT****) analysis for the sanitation system alternatives proposed for* ***UCU,*** *which gives an overall depiction of the system alternatives.*

7.1 Designing of Sanitation Systems.

Variable sanitation systems exist as already discussed in Chapter 3 of this dissertation and the systems can be variably categorised based on inputs managed and treatment processes considered among others. In designing a sanitation system, no sanitation value chain component i.e. user interface, storage or treatment technology is sustainable in itself, instead there are only technologies that serve specific functions within a more or less sustainable system. As such, often the case the system must be planned, designed and operated to suit the specific conditions in which it will operate (Andersson et al. 2016a; Lüthi et al. 2009). To enable sanitation system planning and design, identifying the proposed sanitation system inputs, consideration of the local context, identifying system`s resource management needs and taking into consideration the long-term use of the system are of paramount importance. Thus, understanding the principles of sanitation service provision becomes crucial to informing system designs and planning.

7.2 Principles for Effective Sanitation Service

Given that sanitation systems offer a sanitation service, understanding of the key principles governing effective sanitation service delivery is prudent. Particularly with reference to urban sanitation, the key principles for effective sanitation service delivery are briefly discussed since these principles are the basis on which sanitation systems are designed;

7.2.1 Response to Expectations for Sanitation Service Improvement

Ideally, when providing a sanitation system or upgrading one, the most important principle is the need to respond to users' expectations by providing improved services. The sanitation system should be appropriate with reference to the ability of the users and willingness to pay for service improvements. Successful sanitation planning should incorporate activities that are based on an understanding of the level of interest for sanitation improvements, be if from households, communities town, cities and civic bodies. Thus, a combination of the need for improved sanitation and capacity of institutions would then promote demand and stimulate behavioural change across a range of stakeholders (Parkinson et al. 2014; Lüthi et al. 2011a).

7.2.2 Plan for Inclusive and Equitable Sanitation Services

Taking into consideration that sanitation is recognised by the United Nations as a "Human Right", planning of sanitation systems for urban areas particularly should cover all patches of the area i.e. low-income, informal and illegal settlements. There is no doubt that there may be many constraints to providing sanitation services for all these areas however, relevant city/town authorities need to proactively seek to resolve the constraints. In this way, facilitation of sanitation solutions, which ensure that all residents in the urban areas can access improved sanitation is promoted (Parkinson et al. 2014; Hawkins et al. 2013).

7.2.3 Ensure Sanitation Services are Affordable and Financially viable

Much as sanitation facilities may have been provided, eventual failure of the systems may become eminent unless funds are available to cover on-going operation and maintenance costs for the installed sanitation systems. Even though capital costs may be subsidised, all sanitation systems should aim for sustainable cost recovery to cover operational, regular maintenance and capital maintenance costs (Parkinson et al. 2014; Andersson et al. 2016a).

7.2.4 Integration with other Services

Particularly with reference to urban areas where there is a linkage between the different elements of environmental sanitation i.e. sullage, drainage, solid waste, excreta, it is only prudent that the sanitation services/systems consider an integrated approach where links between sanitation and other services are promoted. To prevent public health challenges related to discharge and poor management of various waste streams handled separately, an integrated approach to managing/handling organic waste streams for example maybe worthwhile, Moreover, integrated approaches to organic waste management for instance provides greater opportunities for efficiencies in service delivery and resource recovery and reuse. This can be achieved through composting of waste streams or anaerobic digestion of a mixture of organic solid waste among other technologies/processes (Parkinson et al. 2014; Andersson et al. 2016a).

7.2.5 Focus on Behavioural Change

As far as achieving full benefits of sanitation with reference to public health outcomes is concern, the appropriate use of sanitation facilities often requires that users make changes to their existing behaviour. Therefore, awareness and behaviour change campaigns become an essential part of planning a sanitation system in addition to proposals to develop infrastructure and facilities for excreta management. Moreover, there is need for behavioural changes at all levels and this may require changing management practices so as to embrace innovations in sanitation system that challenge existing perceptions at political and institutional levels. Thus, in summary the "software" components of sanitation should be incorporated when planning a sanitation system (Parkinson et al. 2014; Peal et al. 2010).

7.2.6 Engage with Stakeholders

Bearing in mind that providing sanitation as a service incorporates both the hardware and software components, engagement with different stakeholder groups is a critical activity that is essential for the successful development of sustainable sanitation services and promotion on behaviour changes. Effective communication with and among local stakeholders would ensure that the relevance of the planning process is determined and would be a motivating factor, influencing active involvement. Such involvement would subsequently motivate the stakeholders to support the implementation of the sanitation system or project. Effective communication between the respective stakeholders, particularly the customers, service providers and regulators is therefore fundamental for sustaining the sanitation system in the long term (Parkinson et al. 2014; Andersson et al. 2016a). In combination with the principles of sanitation service delivery discussed, understanding of key factors that could influence sanitation system design is equally pertinent.

7.3 Factors Influencing Sanitation System Design

Often the case, the factors that influence sanitation system design may be purely technical in nature while other factors may relate to broader aspects of the sanitation system sustainability (Andersson et al. 2016a; Andersson et al. 2016b). The commonly identified factors influencing sanitation system design include;

- Identified demand for recoverable resources e.g biogas for **UCU**
- Geographical and geophysical factors such as water availability, existing infrastructure, natural hazards, population density etc.
- User needs, expectations and capacity.
- Protection of human health and environment
- Institutional capacity and access to local technical support
- Availability of materials for construction, operation and maintenance
- Projected developments such as population density, expansion of the University etc.
- Availability of financial resources for construction and long-term operation

By taking into consideration the principles for an effective sanitation system discussed in combination with the local context of the designated area i.e. **UCU** and surrounding, focus is drawn on specific factors influencing sanitation system design. A brief discussion of these influencing factors is carried out prior to the design the sanitation system options/alternatives suggested for **UCU**.

7.3.1 Geographical and Geophysical Factors.

These factors basically determine what is and is not feasible when planning a new sanitation system or upgrading one. Often the case these factors are site specific and include water availability, topography and geology, trend of natural hazards, urbanisation as well as existing infrastructure. With reference to **UCU,** the current sanitation system is water borne thus, availability of water is necessary to ensure that **WWTP** is operational.

Also, the University is located in Mukono Municipality i.e. an urban setting while the topography at **UCU** currently allows for wastewater from various source points within the University to flow to the **WWTP** by gravity. However, where need be, pumps are used, case in point being the discharge of treated wastewater effluent from the **WWTP** to the drainage trenches.

7.3.2 User Needs, Expectations and Capacity

With reference to **UCU,** one of the main needs for the sanitation system is that further management of sewage sludge would be accomplished, solving the current challenge experienced as far as final disposal of the sewage sludge from the **WWTP** lagoons is concern. The University`s expectations as stipulated in the strategic plan includes sustainable management of the sewage sludge while additionally accruing benefits in the form of biogas, which can then be used as a clean energy source for cooking purposes. In terms of capacity, the **WWTP** currently operates at half its capacity i.e. 160m^3 /day, implying there is a possibility for additional management of wastewater or related waste streams (faecal sludge). Moreover, the **WWTP** is operated and maintained by staff employed at **UCU** thus, the necessary human resource already exists. Upgrading of system would therefore imply new installations as well as increasing the required skilled labour.

7.3.3 Protection of Human Health and Environment

Ultimately, the fundamental function of all sanitation systems is to prevent human contact with hazardous pathogens and chemicals, even though an additional goal of resource recovery can be considered (Andersson et al. 2016a; Andersson et al. 2016b; Lüthi et al. 2009). By taking into consideration related impacts associated with pathogen exposure, the assessment of possible points from which exposure to pathogens or microbial hazards can occur is crucial. Thus, in designing of sanitation system options for **UCU,** exposure to pathogens should be checked, particularly since resource recovery is considered. As such, a well-designed resource recovery sanitation system should incorporate health protection and risk management measures since management of sewage sludge and other organic waste streams is considered.

As initially mentioned in the Chapter 1 of the dissertation, the integrated sanitation systems approach proposed in this research additionally considers reuse of wastewater effluent as process water for the anaerobic digestion process. Recovery of biogas from management of sewage sludge also implies that methane emissions that would otherwise be emitted to the environment as a greenhouse gas, is used as an energy source (Metcalf and Eddy 2004; Al Seadi et al. 2008).

7.3.4 Institutional Capacity and Access to Local Technical Support

Without the proper devolvement of responsibilities to respective stakeholders for sanitation service delivery and clear assignment of system management duties, the best-designed technical sanitation system can be guaranteed to fail. As such, proper structuring, organising and coordination of stakeholders involved would be crucial for effective sanitation service delivery.

Such tasks become mandatory, especially with regards to sanitation systems which additionally consider resource recovery since such systems involve an even greater diversity of actors than conventional systems. Besides, often the case the actors have no prior experience of the sanitation sector thus, the additional complexity of linking in new sectors and stakeholders while ensuring quality service delivery, requires additional institutional arrangements and governance (Andersson et al. 2016a; Parkinson et al. 2014). Therefore, by considering the private and public sector in addition to incorporating socio-cultural aspects relevant to the users, a more comprehensive sanitation system would be designed, operated and maintained if proper institutional and supporting regulatory requirements are defined.

7.3.5 Availability of Material for Sanitation System Phases

This factor is one of the very basic ones since absence of necessary material for construction, operation and maintenance of the sanitation system implies that the system may not be implemented. Therefore, availability of the necessary material locally i.e. within Mukono or Uganda would generally imply reduced costs are incurred in purchasing and transporting material as compared to obtaining the material from external source points (outside Uganda).

7.3.6 Projected Development and Financial resources

Generally, having a plan for future developments, which incorporate sanitation service requirements and the financial resources to enable such developments, are driving factors influencing system design**. UCU** being a private University located in an urban area, increase in student and employee population can be expected. Moreover, the University which has only been in existence for the last 10 years is expanding with additional campuses located in four other districts i.e. Kampala, Kabale, Mbale and Arua. Thus, with the expected development, necessary sanitation infrastructure should also be able to cater for projected population increase. Furthermore, the fact that the University is privately run implies that financial resources to implement required sanitation system improvements would be partly provided by the University management. Additional financial resources in the form of loans or grants can also be obtained to supplement University resources for relevant infrastructural development.

Taking into consideration the principles for effective sanitation service delivery and the factors influencing sanitation system design, six sanitation system alternatives were designed for **UCU** as discussed.

7.4 Sanitation System Alternatives

The design of the six sanitation system alternatives was also informed by other relevant tools such as the compendium of sanitation systems and technologies and related literature. Furthermore, consideration of the various system inputs or waste streams i.e. sewage sludge, kitchen waste, cow dung, sewage and faecal sludge and wastewater effluent, influenced the choice of technologies/processes considered for various sanitation system designs.

The various processes for management of the organic waste streams from **UCU** and Mukono Municipality area included; pretreatment, biological stabilisation i.e. anaerobic digestion and composting, solar drying and incineration among others (Wiechmann et al. 2013; Metcalf and Eddy 2004; Tilley et al. 2014).

7.4.1 Status Quo Alternative

This system alternative represents the current measures applied for management of the organic waste streams at **UCU**. In the **Status quo** alternative, management of sewage sludge and other organic waste (kitchen waste and cow dung) is carried out separately. The system considers sewage sludge from the **WWTP,** which is pumped to a $15m^3$ gravity settling tank where the sludge is initially dewatered. On a weekly basis the dewatered sludge consisting about 2.17% **TS** is then channeled to either of the $30m^2$ lagoons while the more liquid portion of sludge is sent back to the **WWTP**. Sewage sludge is then left in the lagoon for a duration of one year where further dewatering, thickening and partial stabilisation takes place. The partially stabilised sewage sludge with **TS** 11% would then be manually dug out from the lagoon and about 30% is used by local farmers as conditioner and also applied at **UCU** Sports field. The leftover partially stabilised sludge (about 70%) is retained in the lagoons, posing a disposal challenge to **UCU.**

Other organic waste generated from **UCU** is considered to be managed in various ways i.e. kitchen waste composed mainly of food remains (75%) and food peelings (25%) is collected by interested local farmers and used as animal feed. While some of the cow dung generated from the University farm is used by local farmers as soil conditioner in nearby gardens and the remnant is dumped in the animal kraal. Figure 7-1 shows the schematic diagram of the **Status Quo** sanitation system alternative.

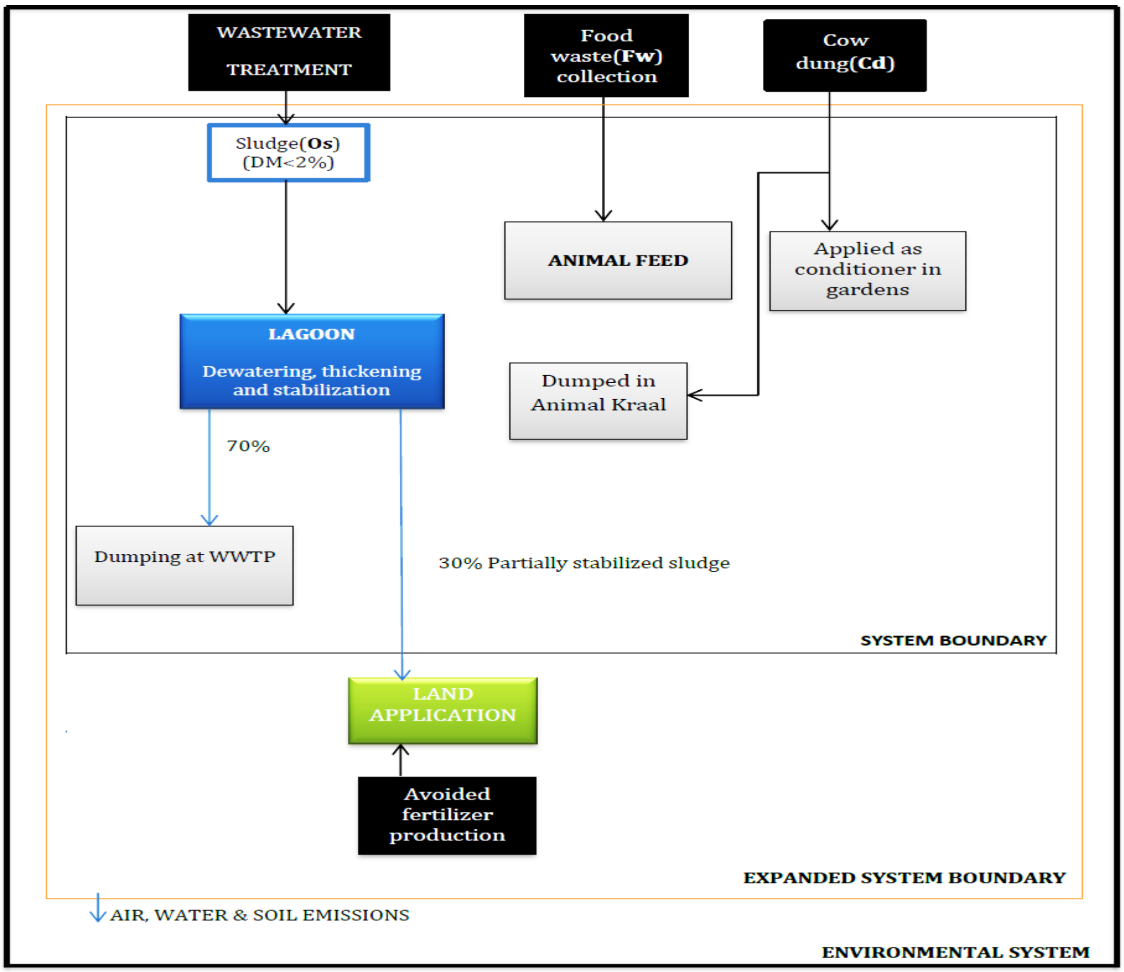

Figure 7-1: Status Quo sanitation system
Source: Author

7.4.2 COMPAD Alternative

The composting and anaerobic digestion (**COMPAD)** sanitation system alternative design considers co-composting of partially stabilised sewage sludge from the lagoon with other organic waste from the University. Co-composting of sewage sludge with other additional organic waste streams allows for further stabilisation of sewage sludge and reduction of pathogen content in addition to volume reduction (Kuo et al. 2004; FEA 2014; Metcalf and Eddy 2004). Tilley et al, (2014) point out that co-composting of sewage sludge with other organic material is viable as long as organic material is available. Moreover, (Metcalf and Eddy 2004) suggest that the composting mix should have a volatile solid content **(VS/oTS)** greater than 30%. Thus, co-composting of sewage sludge with organic material such as compound grass cuttings, wood shavings from the University carpentry and food peelings from the kitchen is considered for **UCU** (Metcalf and Eddy 2004; Tilley et al. 2014).

The additional organic material also referred to as amendment should boost reduction in bulk weight, moisture content and increase air voids enabling the composting process. Also, wood shavings, sawdust and compound cuttings contain cellulose which improves the carbon to nitrogen (C/N) ratio required to boost composting process (FEA 2014). For the composting process, sewage sludge from the lagoon was preferred to sewage sludge obtained directly from the **WWTP.** This is because sewage sludge from the lagoon would be partially dewatered implying the amount of vapor to be evaporated by the composting process would be reduced. Also, sludge from the lagoon consists of more solid content at **TS** 11% compared to **TS** 3% for sludge from **WWTP**(Metcalf and Eddy 2004; FEA 2014).

Moreover, consideration of sewage sludge from **UCU** for co-composting was influenced by sewage sludge quality. Analysis of sewage sludge sample from **UCU** lagoon at the National Government laboratory in Uganda showed that the heavy metal content in the sewage sludge was way below the standard values stipulated by both the European Union directive and the United States standards(**EPA**[17]) for sewage sludge application in land (EPA 1994; EC 2001). The analysis also showed significant content of nutrients such as potassium, nitrogen and phosphates as shown in Table 7-1 and the analysis report attached in Appendix 4. Reference to the **EPA** standards and Directive **86/278/EEC** for sewage sludge application on land was considered mainly because specific regulations for quality of biosolids application on land do not exist for Uganda. Based on laboratory analysis of sewage sludge sample from **UCU**, fears related to heavy metal contamination caused by utilisation of compost produced from co-composting sewage sludge and organic waste are allayed.

Table 7-1: Summary of Sewage Sludge Sample Laboratory Analysis-Reference to International Standards for Biosolids Application

Parameter	Mean Values UCU Sample-a	EPA ceiling concentration limits for all biosolids applied on land	EC ceiling concentration limits for all biosolids applied on land
Cadmium(mg/Kg)	<0.001	85	20-40
Copper(mg/Kg)	7.5010	4,300	1000-1750
Nickel(mg/Kg)	<0.001	420	300-400
Lead(mg/Kg)	<0.001	840	750-1200
Zinc(mg/Kg)	29.1073	7,500	2,500-4,000
Potassium (mg/Kg)	47.3979		
Total Nitrogen(mg/Kg)	2.26		
Phosphorus(mg/Kg)	4.90		

Sources: Government Analytical Laboratory, (EPA 1994), (EC 2001)

[17] **EPA**: United States Environment protection Agency whose mission is to protect human health and the environment

Despite the dewatering of sewage sludge from the lagoon, a **TS** of 11% resulted yet a **TS** in the range of 20-30% can be achieved in case well-structured lagoons and climatic conditions are considered (Metcalf and Eddy 2004). The slightly lower **TS%** value of sewage sludge from **UCU** lagoons was attributed to the open nature of the lagoons which affected the drying process, especially during rainy season. Therefore, recommendations for infrastructural improvements of the lagoon to include roofing structure were considered. These improvements would ensure that the sewage sludge **TS** of up to 30% is attained.

Co-composting of the sewage sludge with organic waste over a duration of atleast 10 weeks in windrows or heaps is proposed. Windrow composting is considered since it is recommended for cases where management of large organic waste quantities is envisioned (FEA 2014; Metcalf and Eddy 2004). Also, the availability of space within the **WWTP** for installation of a composting unit reinforced the choice of windrow composting considered. Utilisation of generated compost by interested customers as soil conditioner in agriculture, horticulture or landscaping is then taken into consideration.

The **COMPAD** alternative also considered anaerobic digestion of other organic waste i.e. food waste (**Fw)** and cow dung (**Cd**). In so doing, energy recovery from biogas and nutrient recovery from digestate is expected. Consideration of **Cd** and **Fw** for anaerobic is based on **UCU`s** interest in biogas for cooking, which is justified by the good performance of **Cd:Fw** co-digestion shown experimentally (refer to section 6.8.2 and 6.8.3). A vertical continuous stirred tank reactor **(CSTR)** is proposed as the anaerobic digester and would consist of necessary components for stirring, heating and gas storage. The choice of the digester was informed by the substrate characteristics i.e. sewage sludge, cow dung, food waste and faecal sludge, which would require mixing. In addition, other process conditions such as the organic loading rate (**OLR**) of at least 2 (kg VS/m^3), minimum hydraulic retention time(HRT) of 30 days and digester mesophilic conditions (30-42°C) already discussed in Chapter 6 informed the choice of digester considered (Al Seadi et al. 2008;Vögeli et al. 2014). Therefore, installation of a biogas digester preferably near the kitchen where wet anaerobic co-digestion of **Cd** and **Fw** is considered.

The proposed collection of **Cd** from the University farm located about 3.5km from **UCU** campus is taken into consideration. While **Fw** would be obtained from the University kitchen. Pre-treatment of **Fw** which would include sorting and size reduction prior to mixing with **Cd** at a ratio **Fw: Cd 70:30** is also taken into consideration. In addition to the digester design conditions already mentioned, utilisation of biogas from the anaerobic co-digestion is proposed in two scenarios; direct utilisation of biogas as cooking fuel, substituting cooking energy needs from firewood or combustion of biogas in a **CHP** unit, generating electricity and heat. These scenarios were proposed to attain necessary information on preferred mode of biogas utilisation for **UCU**.

A small **CHP** unit of at least 50kW power rating is considered and has an overall efficiency of 83% with an electricity conversion of 31% and heat output of 52% (Renac 2014; Al Seadi et al. 2008). Electricity generated from the CHP unit would be used to supplement electricity demand within the University while heat generated would be considered for heating water, eventually used for cooking purposes. Finally, digestate from the anaerobic digestion process is considered for application as organic fertilizer, substituting mineral fertilizer production and use. With reference to the integrated sanitation system entry points identified for urban areas in Uganda(refer to Chapter 3), the general design concept of the **COMPAD** alternative can be considered for institutions of learning, housing estates, and possibly peri- urban areas, where there is available land to install a composting unit. This basically implies that specificities regarding substrate composition may be adjusted with respect to substrate availability and overall goals of the sanitation systems. Figure 7-2 shows a schematic diagram of the **COMPAD** sanitation system alternative.

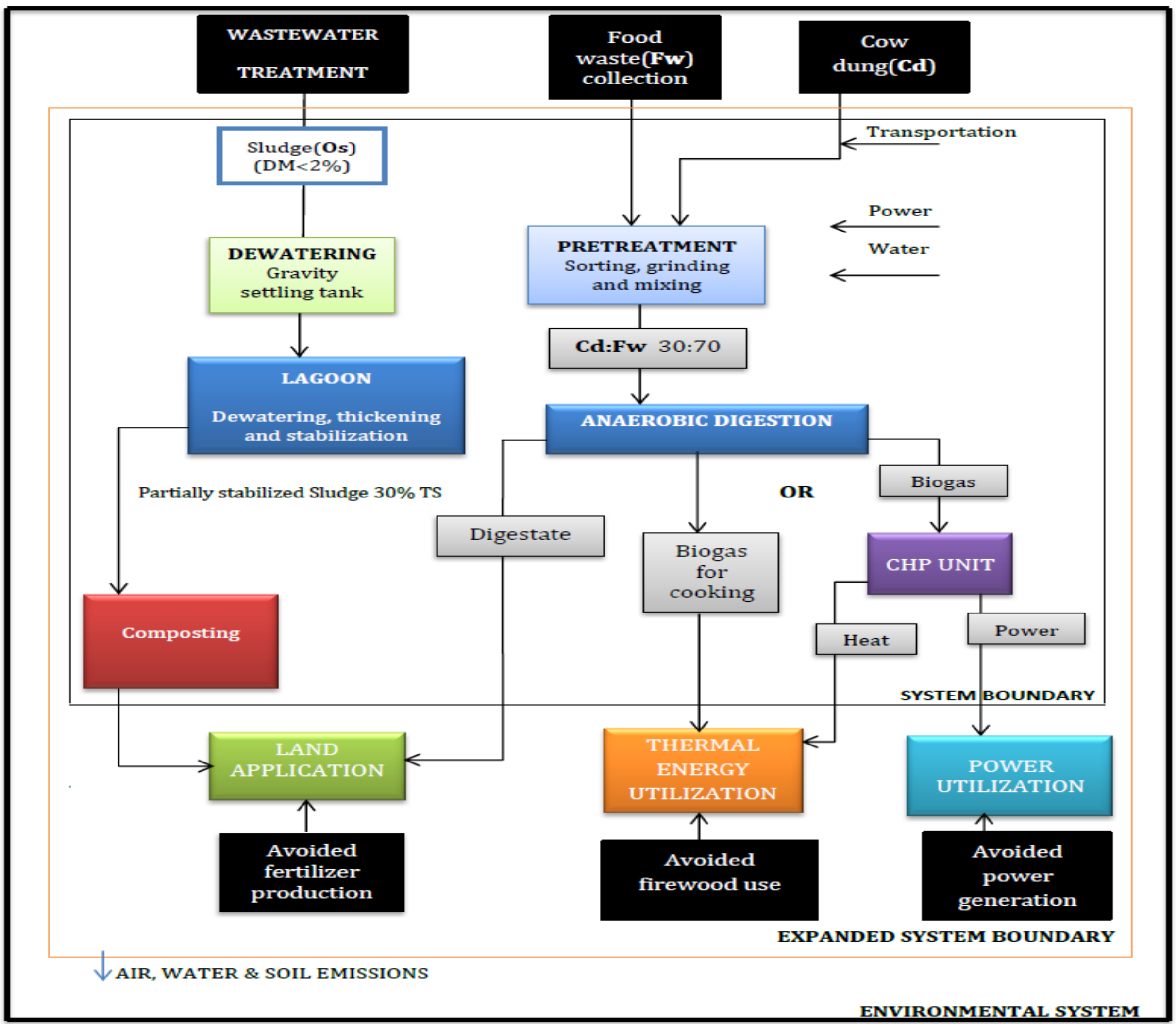

Figure 7-2: COMPAD sanitation system alternative
Source: Author

7.4.3 COMPAD LF Alternative

The anaerobic digestion and composting at Mukono Municipal landfill (**COMPAD LF)** alternative is similar to the **COMPAD** alternative in most aspects, except co-composting of sewage sludge with organic waste is proposed at Mukono Landfill which is located about 7Km from **UCU**. The landfill already has an operational composting plant which currently composts only organic waste.

This alternative is considered with reference to the availability of a composting plant, necessary labour to carry out required activities in addition to constant supply of organic waste at Mukono landfill. Direct involvement of **UCU** in the co-composting process would be reduced, avoiding odor problems and leachate management concerns associated with open composting (FEA 2014; Metcalf and Eddy 2004). A memorandum of understanding between **UCU** and Mukono Municipality authorities would be required to clearly define roles of engagement for both institutions. **UCU** would additionally incur costs for transportation of the lagoon stabilised sewage sludge to the landfill.

In terms of similarity to the **COMPAD** alternative, the **COMPAD LF** alternative also considers anaerobic digestion of **Cd** and **Fw** and all respective processes for biogas and digestate management are similar. Thus, this sanitation system alternative caters for scenarios where collaboration opportunities exist between institutions and various authorities etc. With reference to the identified entry points for integrated sanitation systems in urban areas of Uganda, general design aspects of the **COMPAD LF** alternative could be considered for housing estates, other institutions of learning as well as peri-urban areas and cities or major towns. The fact that about 17 composting plants have been installed within district/town landfills is also a driving factor for the consideration of this sanitation system alternative for towns and cities. Figure 7-3shows a schematic diagram of the **COMPAD LF** sanitation system alternative.

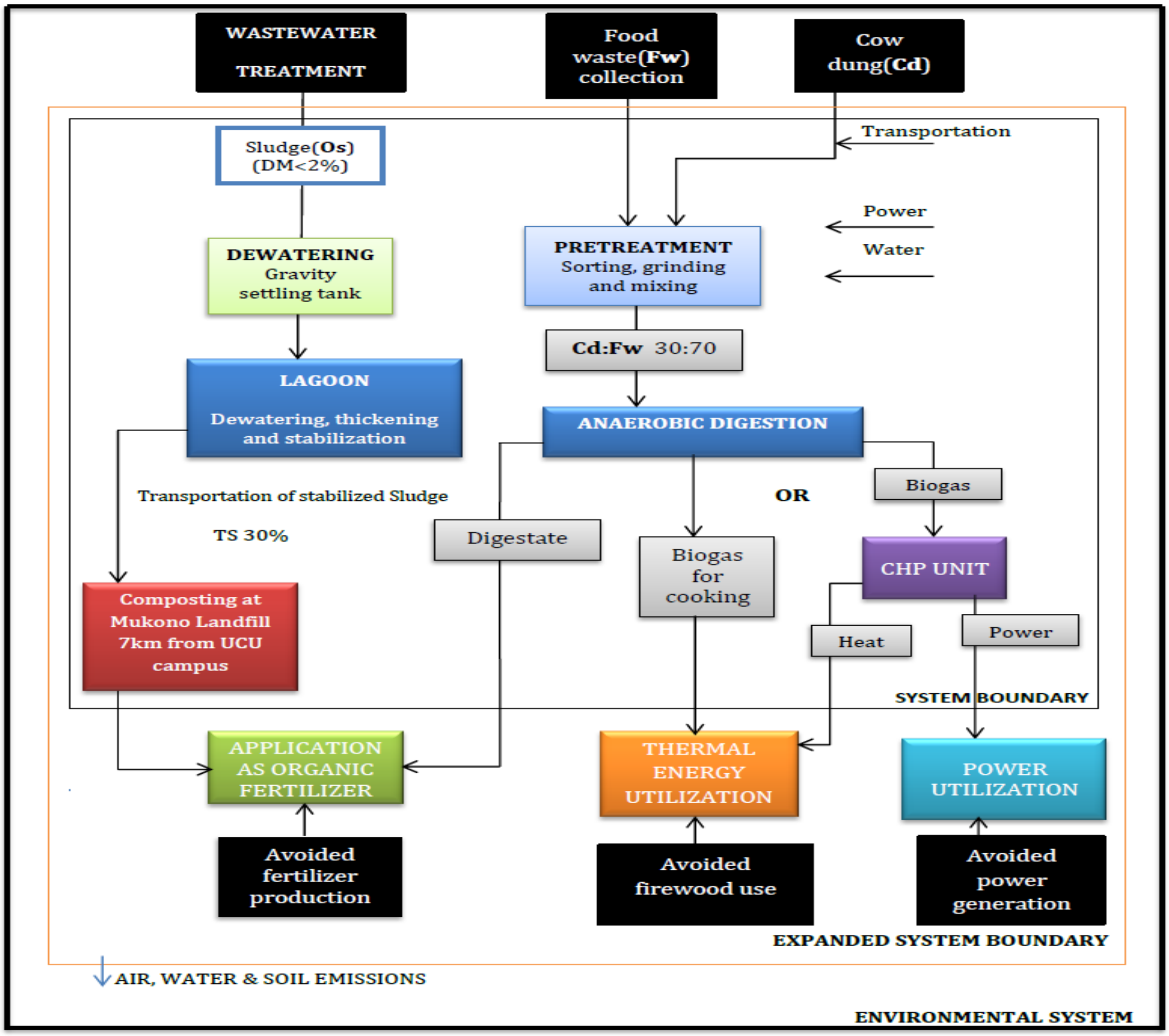

Figure 7-3: COMPAD LF Sanitation system alternative
Source: Author

7.4.4 INCAD Alternative

The incineration and anaerobic digestion **(INCAD)** alternative considers incineration of sewage sludge as a management measure. Although there are a few examples of incineration of sewage sludge in Africa with mainly South Africa cited as an example, the technology is quite mature in developed countries such as Japan, Germany, United Kingdom and USA. It is no doubt that large scale application of incineration for management of sewage sludge is well documented in most of the developed countries mentioned(Reddy 2016; Wiechmann et al. 2013; MoEJ 2012; Luckos and Hoed 2011).

However, the need to consider incineration of waste for smaller communities, or establishments such as hospitals, institutions, small towns to mention but a few, has influenced small scale incineration technology innovation (Johansson and Warren 2015; MMIS 2010). Variable ranges of small scale incinerator capacities exist with some combusting as low as 12-100kg/h of waste. For small scale incinerators processing very small amounts of waste, resources recovery in the form of heat and electricity is at times considered not feasible. Nevertheless, continuous innovations and advancement in waste to energy technologies have resulted in development of small scale incinerators, which also have provisions for energy recovery, are modular in nature and in certain cases are even mobile (Chen et al. 2005; Chen et al. 2008; Niklas 2014).

Experiences from Japan particularly showed that small scale incinerators, which processed less that 50tones of waste a day constituted at least 60% of total number of incinerators in the country in the year 2000. Literature shows that good numbers of these incinerators were later shut down due to cost implications related to meeting stringent emission control requirements. Nevertheless, an acute need for small-scale incinerators for the purposes of disease control, environmental sanitation, and budget saving in rural areas and remote communities has continued to influence innovations in other countries as well (Chen et al. 2008; Johansson and Warren 2015). An example of such small scale incinerator innovations includes one which incorporates a cyclone energy recovery system and has a processing capacity of 1.5tone/day. The incinerator is feasible if the moisture content of waste incinerated is less than 31% (Chen et al. 2005).

On the other hand, the small-scale modular incinerators feature heat recovery as steam or hot water and usually forego materials recovery. While the mobile incinerator units as the name suggests can be moved from place to place and may include energy recovery provision in addition to a diesel run generator set for ignition (Niklas 2014; Ellyin 2012). Overall, the limited application of sludge incineration in Africa has been mainly attributed to the related high capital and operation costs associated with incineration (Herselman et al. 2006).

With reference to such a background, the design of the **INCAD** alternative for **UCU** was inspired by the fact that the University plans to install a state-of-the-art incinerator for management of medical waste from the University clinic and medical department. As such, infrastructure and manpower to enable co-incineration of medical waste with sewage sludge would be available. Furthermore, that fact that there is limited documentation in the region regarding small scale application of incinerators for management of sewage sludge with provision for resource recovery also motivated the consideration of this alternative. As such, the **INCAD** alternative proposed could be a pioneer plant in the country and avail the much needed information on incineration of sewage sludge.

With regards to the technical feasibility of sewage sludge incineration, a **TS** content of digested sewage sludge in the range 45 to 55 % is required (Wiechmann et al. 2013; FEA 2014). Hence, with reference to **UCU** context, drying of sewage sludge from the lagoon to improve **TS** content from 11% to at least 50% is considered in this design. The solar dried sewage sludge would then be co-incinerated with medical waste. Solar drying of the sewage sludge is considered an affordable technique especially for areas where solar radiation is easily available. A solar drying unit with design provisions for in wall structure, transparent roofing and moisture excavations is considered. Sewage sludge would then be dried either through batch or continuous processes in the solar drying bed. Frequent turning and intermixing of the already dried and still wet portions of sewage sludge should ensure good drying efficiency (FEA 2014). Similar to the **COMPAD** alternative, the planned location of the solar drying bed would be near the sewage lagoons at the **WWTP**. This would limit any additional sewage sludge handling and transportation logistical requirements.

Provisions for air pollution control from co-incineration of sewage sludge and medical waste in the incinerator should be catered for to ensure ambient air quality and human health. Also, the requirement of skilled labor to operate and manage the incineration process, including checking emissions from the process, are key aspects to be considered for **INCAD** alternative(Herselman et al. 2006; Johansson, and Warren 2015).

Anaerobic digestion of **Cd** and **Fw** mixture **Cd: Fw 30:70** is additionally considered for the **INCAD** alternative**.** All other processes related to anaerobic digestion of **Cd: Fw** are handled in a similar manner to **COMPAD** and **COMPD LF** alternatives. Additional recovery of energy from the incineration process in form of waste heat is also taken into account. The **INCAD** alternative caters for scenarios were incineration technology is available and can be additionally applied for sewage sludge management. Thus, general design aspects for the **INCAD** alternative can be considered for use in hospitals and housing estates where provision for incineration of certain waste streams exists. In addition, towns and or cities which have incineration units or where plans for such systems are underway can be considered. Figure 7-4 shows the schematic diagram of the **INCAD** sanitation system alternative.

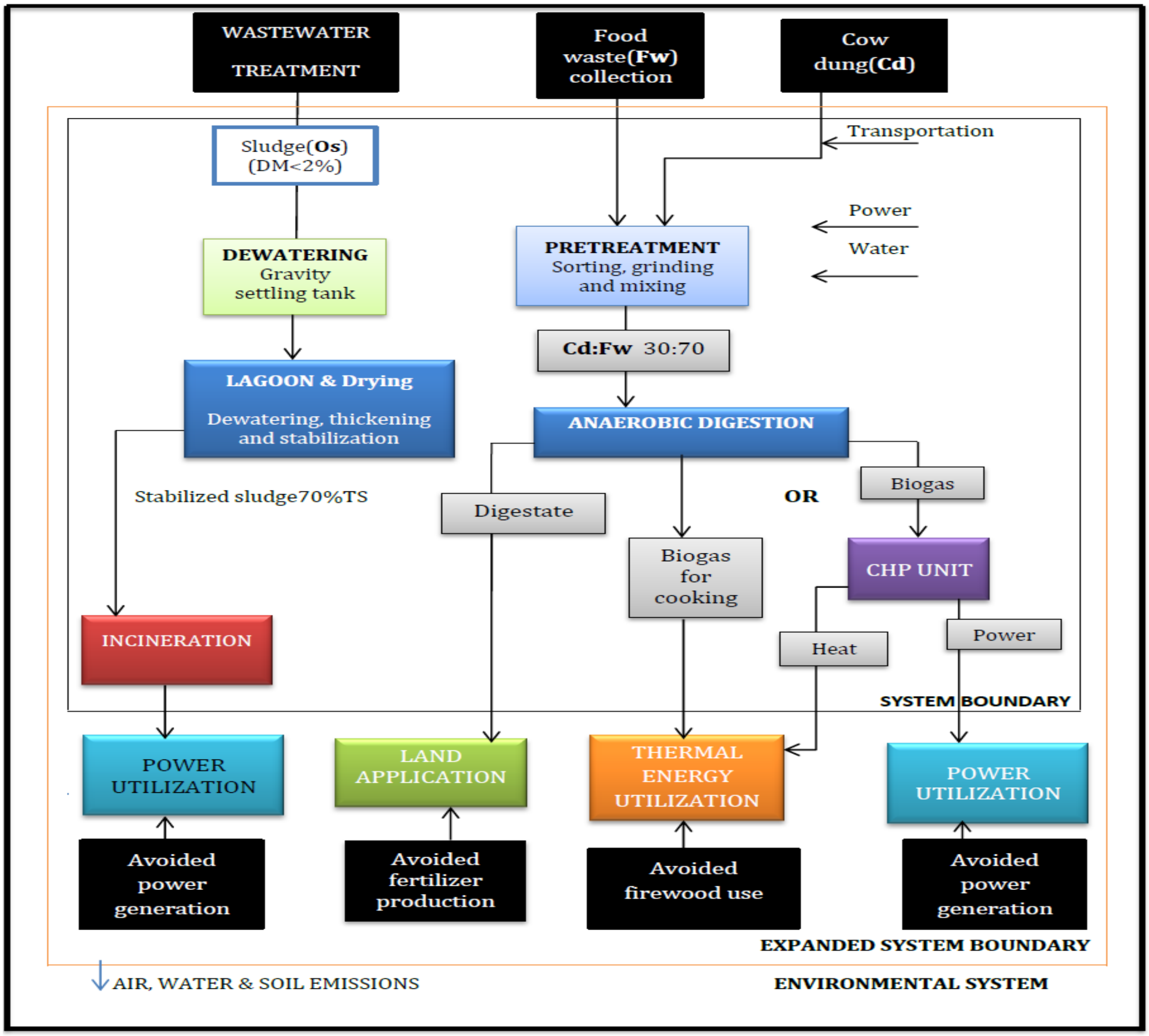

Figure 7-4: INCAD Sanitation system alternative
Source: Author

7.4.5 INTEG 1 Alternative

The Integrated sanitation system **(INTEG 1) alternative** considers an integrated approach where combined management of sewage sludge (**Os**), other organic waste (**Cd** and **Fw**) is accomplished using anaerobic digestion. Co-digestion of **Os:Cd:Fw 30:20:50** is considered based on **UCU`s** interest to generate biogas from sewage sludge further justified by findings from experimental analysis discussed in **section 6.6**. For the **INTEG 1** alternative, installation of a biogas digester at the **WWTP** is considered**,** lessening logistical requirements for handling sewage sludge. Sewage sludge (**Os**) from the settling tank with **TS** of 2.17% would be mixed with pre-treated **Fw** and **Cd** prior to anaerobic digestion**.**

Additional water requirements for substrate mixing would be supplied by treated effluent from the **WWTP,** reducing the water foot print for the anaerobic digestion process and emphasising an integrated approach**.** Justification for the reuse of effluent as process water was attributed to the fact that laboratory analysis of wastwater effluent showed compliance to national standards for effluent discharge attached in Appendix 4. Compliance of the effluent from **UCU WWTP** with national discharge standards implied that effluent showed good physical-chemical and bacteriological characteristics. As such, any anticipated bacterial transmission during reuse of effluent as process water would be checked.

Biogas produced from anaerobic digestion would be utilised either directly for cooking or generation of electricity and heat from the **CHP** unit. Digestate produced from the anaerobic digester would be directed to the lagoon where it would be dewatered, thickened and further stabilised. Since digestate is mainly liquid i.e. 2- 6% **TS**, the digestate would be left for a period of atleast 6months, allowing for volume reduction, further stabilisation and pathogen reduction (Drosg et al. 2015; Al Seadi et al. 2008). After the 6 month period in the lagoon, solar dying of digestate is considered to ensure that possible users of digestate as organic fertilizer are not exposed to any health safety threats from pathogens. Furthermore, portability of solar dried digestate would be improved since a **TS** in the range 60**-** 70% can be attained.

INTEG 1 alternative caters for scenarios where in addition to combined management of waste streams, user perceptions or attitudes do not affect utilisation of by products from anaerobic digestion process. General design aspects of the **INTEG 1** alternative can be considered for institutions, housing estates, peri-urban areas and towns or cities. Quality assurance of the digestate proposed for use as organic fertilizer would be necessary for city and or town systems since the sources of sewage sludge may include wastewater or sludge from industrial source points. Figure 7-5 shows a schematic diagram of the **INTEG 1** sanitation system alternative.

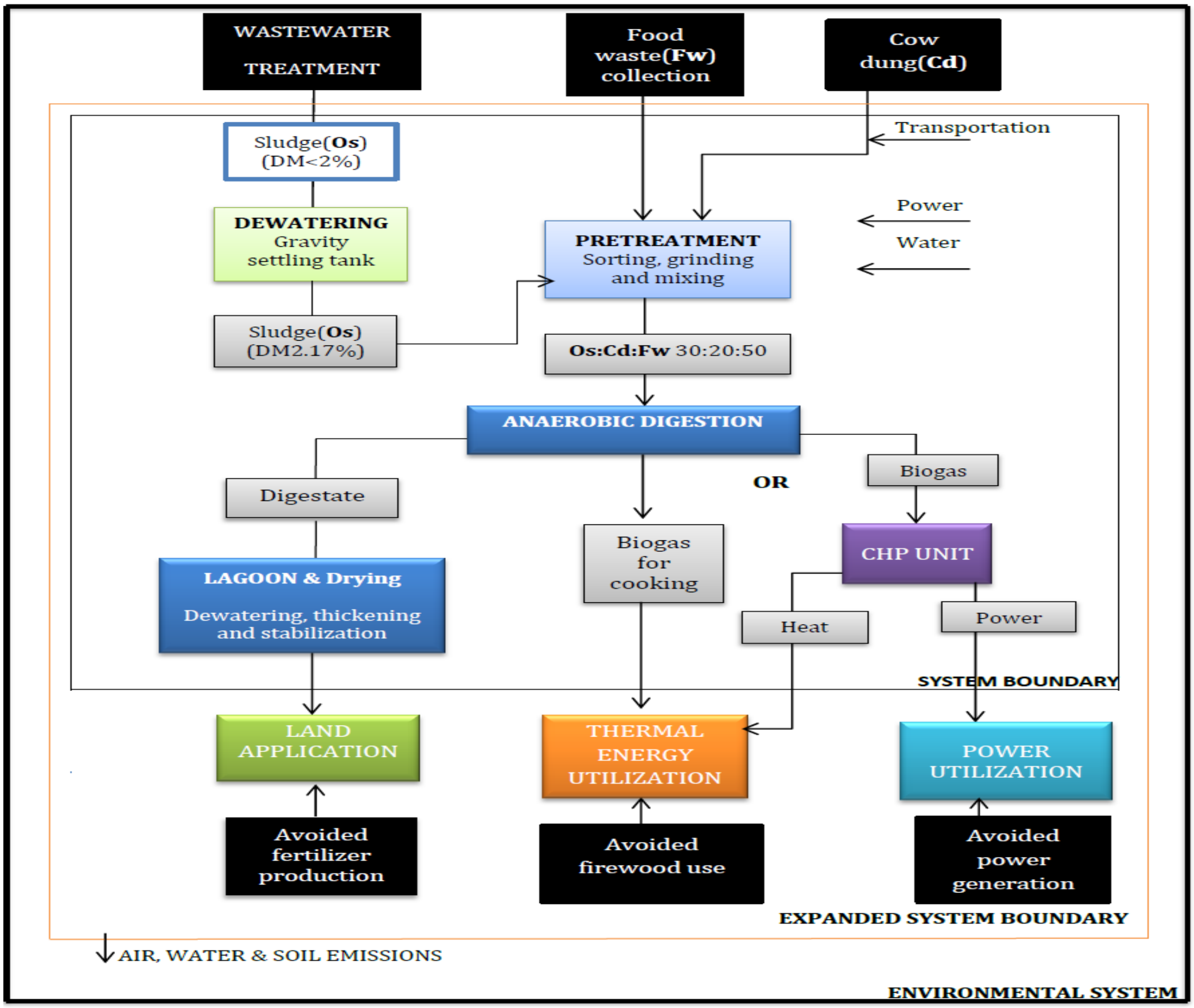

Figure 7-5: INTEG 1 Sanitation system alternative
Source: Author

7.4.6 INTEG 2 Alternative

The integrated sanitation system 2 **(INTEG 2)** alternative is similar to **INTEG 1** but additionally considers anaerobic digestion of faecal sludge (**Fs**). As already highlighted in Section 6.2, Mukono town does not have a **WWTP** and faecal treatment plant and yet sewage and faecal sludge from onsite sanitary facilities has to be managed (Strande et al. 2014; Tilley et al. 2014). The fact that the **WWTP** at **UCU** currently operates at half its capacity additionally motivated the design of the **INTEG 2** alternative. As such, co-digestion of **Fs:Os:Cd:Fw 10:20:20:50 or 10:20:30:40** is considered**.** For the technical viability of **INTEG 2,** non-biodegradable solids i.e. pads, plastics etc. often found in faecal sludge should be sorted. Moreover, the liquid portion of the faecal sludge can be directed to the **WWTP** for treatment so as to limit exposure to pathogens.

Therefore, installation of a separation unit where faecal sludge would be sorted prior to mixing with other organic waste streams for anaerobic digestion is considered in the system design. Selective collection of faecal sludge from source points that cater for separated disposal could reduce the pretreatment and handling requirements. For example, faecal sludge from septic tanks could be given priority instead of faecal sludge from pit latrines.

Proposed installation of the biogas digester and faecal sludge separation unit at the **WWTP** is considered so that any logistical requirements for handling of sewage and faecal sludge are reduced. Similar to the **INTEG 1** alternative, reuse of effluent from the **WWTP** as process water for the anaerobic digestion process is considered with the aim of reducing the water foot print for the process**.**

Biogas generated from the anaerobic digestion process would be handled as suggested for all other alternatives. While 60% of the digestate generated would be handled as suggested for the **INTEG 1** alternative. Moreover, 40% of the solar dried digestate is considered for briquette making, which is inspired by promising examples of fuel recovery from faecal sludge material and attractiveness of digestate as fuel (Gold et al. 2016; Kratzeisen et al. 2010). The decision to consider 60% of the digestate as organic fertilizer and 40% for briquetting was inspired by the fact that after the anaerobic digestion process, the digestate has less organic carbon and hence would have a lower calorific value than briquettes from wood shavings for instance (Kratzeisen et al. 2010; Al Seadi et al. 2008). As such, only a portion of the digestate (40%) is considered for making briquettes while the 60% remnant is used as organic fertilizer. Further modifications with regards to amount of digestate utilised for briquette making and as organic fertilizer can be considered based on the priorities of the University.

To guarantee the quality of digestate considered as organic fertilizer, compliance with **EPA** standards and the **EC** directive on application of biosolids on land is recommended. Moreover, additional comparison of digestate quality values with stabilised conditioner from **NWSC**[18] faecal treatment plants for instance could additionally win the trust of potential customers. Table 7-2 gives a summary of the **EPA** standards and **NWSC** manure quality results.

[18] **NWSC**: National water and sewerage corporation, Uganda which is public utility company owned by the Government of Uganda operating and providing water and sewerage services in the larger urban centres.

Table 7-2: Summary of EPA standards and NWSC manure quality results

Parameters	**NWSC** Lubigi Values As at 03.2016-[a]	Maximum concentrations in sewage sludge for land application(EPA 1993)-[b]	EC ceiling concentration limits for all biosolids applied on land-[c]
Nitrogen (mg/Kg)	3133.50		
Phosphorus (mg/Kg)	5067.00		
Potassium (mg/Kg)	63.64		
Mercury (mg/Kg)	0.00		16-25
Lead (mg/Kg)	15.89	840	750-1200
Cadmium (mg/Kg)	1.19	85	20-40
Chromium (mg/Kg)	26.26	3000	750-1200
Copper (mg/Kg)	107.10	4300	1000-1750
Zinc	221.75	7500	2500-4000

Sources: a-(Malambala 2016), b- (EPA 1994), c- (EC 2001)

INTEG 2 alternative caters for scenarios where services can be additionally offered to neighbouring communities i.e. management of faecal sludge at **UCU,** which adopts an all-inclusive approach to sanitation (Hawkins et al. 2013; Parkinson et al. 2014). Furthermore, production of briquettes from dried digestate increases resource recovery in the form of cooking fuel from the sanitation system. This further promotes a more circular than linear cycle approach to sanitation (Andersson et al. 2016a; Andersson et al. 2016b). General design aspects of the **INTEG 2** alternative can be considered for peri- urban areas, towns as well as cities where variable settlement groups may be found. Figure 7-6 shows a schematic diagram of the **INTEG 2** sanitation system alternative.

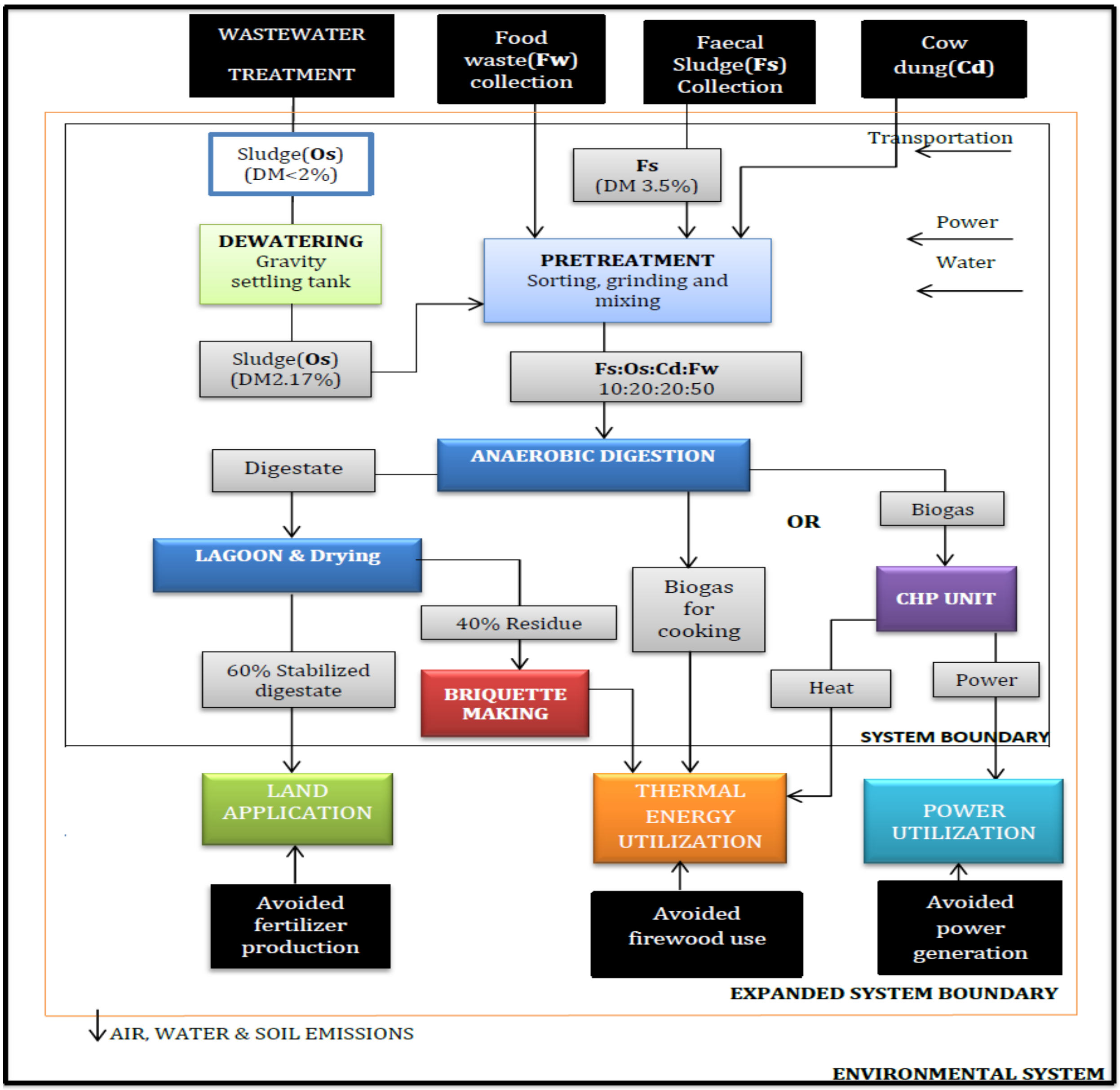

Figure 7-6: INTEG 2 Sanitation system alternative
Source: Author

Table 7-3 shows a summary of technical feasibility conditions for key technologies/processes considered in the different sanitation system designs.

Table 7-3: Summary of Technical Feasibility of Technologies/Processes Considered.

No	Technology/process	Technical Feasibility	Considerations for UCU systems
1	Anaerobic digestion CSTR(a,b,c)	• Generally, plant sizes starting from 15kW are feasible • Substrates with dry matter content (TS) of 10 to15% are suitable. • Under mesophilic condition, mesophilic, temperature ranges of 35°C to 40°C considered • The organic loading rate (OLR) between 2 and 4 kgVS/m^3 digester volume can be considered • Hydraulic retention time(HTR) of at least 30 days can be considered	• Plant size range from 450-850Kw • Substrate dry matter content (TS) ranges between 2.17-27% • Mesophilic digester conditions considered • OLR ranging between 2-2.5 kgVS/m^3 considered • HTR of at least 30 days
2	Co-composting (d,e)	• Applicable in both small and large scale i.e household level-commercial plants • Compost mix should be at least 30% dry solids for adequate composting in windrows • Initial C/N ratio should be 20:1 to 35:1 • Moisture content of composting mixture should be atmost 60% for windrow composting • Temperature in composting pile should be maintained between 55 and 60°C • To kill pathogens, minimum process temperatures of 55°C should be maintained for atleast 2 weeks	• Community and commercial composting plants considered • Other conditions are similar to those stated for feasibility of composting process
3	Co-incineration-(f,e,g)	• With reference to small scale units, incineration of 12-1500kg/h of waste is feasible • Sewage sludge must have a total solid content (TS) in the range of 25-30% • Temperature ranges of incinerators are 500°-1450°C • Sludge ratio in mix can be at least 20%	• Incineration of at least 100kg/h of waste is considered • Other conditions are similar to those stated for feasibility of composting process
4	Solar drying (f,d)	• Depends on mode of operation i.e, executed as continuous or batch process under transparent roofs • Frequent turning of mixture required • Up to 85% dry solid content can be reached	• Atleast 70% TS for dried digestate is expected from solar drying unit

Sources; a- (GIZ 2016), b- (Al Seadi et al. 2008), c- (Vögeli et al. 2014), d- (Metcalf and Eddy 2004), e- (FEA 2014), f- (Chen et al. 2008),g- (Chen et al. 2005).

Figure 7-7 shows the potential sites within **UCU** campus where various sanitation system components could be located.

	
Possible location for digester and other system components near the kitchen(**COMPAD,COMPAD LF** and **INCAD**)	Possible location for digester and other system components at the **WWTP (INTEG 1** and **INTEG 2).**

Figure 7-7: Possible locations for digester and other system components within UCU
Source: Author

Having designed the sanitation system alternatives proposed for **UCU**, the next stage of the research with reference to the conceptual framework is to carry out holistic feasibility assessments of the systems proposed. The feasibility assessment of the sanitation system alternatives allows for preliminary understanding of the systems prior to selection. During the feasibility assessments, a combination of participatory approach and assessments using various tools is carried out. Section 7.4.7 focuses on the technical feasibility assessment of the sanitation systems proposed for **UCU**.

7.4.7 Technical Feasibility Assessment of Sanitation System Alternatives

To enable the technical feasibility assessment of the sanitation system alternatives proposed for **UCU**, the criteria initially considered i.e robustness, flexibility and complexity of sanitation systems were further defined using specific indicators. Thus, the indicators considered factored in the local context and intended use of the system alternatives i.e. management of organic waste streams. The definition of indicators was carried out by the researcher with input from relevant stakeholders. Once the relevant indicators were defined and selected, stakeholders assessed the various sanitation system alternatives proposed for **UCU.**

The stakeholders involved in this process included; personnel from the engineering and planning unit as well as engineering-sanitation lecturers at **UCU.** In addition, experts in the fields of sanitation, biogas, faecal sludge management, environmental management and energy sectors in Uganda also participated in the assessment of sanitation system alternatives. A summary of the description of the criteria and indicators considered for technical feasibility assessment and the respective scales is included in Table 7-4.

Table 7-4: Description of Indicators for Technical Feasibility Assessment of Sanitation System Alternatives

Criteria and indicators	Units/scale	Scale description	Description
Robustness			
Sensitivity of sanitation system to shock loads	Low sensitivity=10 Moderate sensitivity=5 High sensitivity=0	***Low sensitivity*** *overall impact of shock loads on sanitation system performance is negligible.* ***Moderate sensitivity*** *impact of shock loads on performance of sanitation system is moderate.* ***High sensitivity*** *impact on sanitation system performance due to impact of shock loads is significant.*	Effect on sanitation system performance due to shock loads caused by absence or fluctuation of electricity, organic waste as inputs, variation in operation parameters (temperature, ph.) and irregular maintenance.
Risk of sanitation system failure	Low risk;=10 Medium=5 High=0	***Low risk*** *possibility of sanitation system failure is negligible.* ***Medium risk*** *occurs when failure in certain components of sanitation system does not result in failure of entire system.* ***High risk*** *occurs when variation in operation parameter and climatic conditions can result in failure of entire system.*	Failure of sanitation system to adequately manage/treat organic waste. Failure could be due to variation of operation parameters (temperature, ph.), impacts due climatic conditions among others.
Complexity of sanitation system			
Possibility to utilise locally available material and labor for construction of sanitation system	Low =0 Medium= 5 High=10	***Low****; External expertise and imported material required for construction/installation of entire sanitation system.*	Construction of sanitation system achieved using locally available material and skilled labor/expertise.

		Medium; *A combination of locally available skilled labor, external expertise, locally available and imported material required for construction/installation of sanitation system.* ***High***; *Construction/installation of entire sanitation system can be accomplished using locally available material and skilled labor.*	
Possibility to utilise locally available labor for operation & maintenance of sanitation system	Low=0 Medium=5 High=10	***Low***; *External expertise required for operation & maintenance of entire sanitation system.* ***Medium***; *A combination of locally available skilled labor and external expertise required for operation and maintenance of the sanitation system.* ***High***; *locally available skilled labor/expertise sufficient for the operation and maintenance of the entire sanitation system.*	Operation and maintenance of sanitation system can be achieved by locally available skilled expertise.
Flexibility			
Adaptability of sanitation system to new conditions and requirements	Low= 0 Moderate=5 High=10	***Low;*** *adaptation of sanitation system cannot be achieved without major modifications.* ***Moderate****; adaptation of sanitation system can be achieved with minor modifications.* ***High;*** *adaptation of entire sanitation system can be easily achieved.*	The ease with which the sanitation system can adapt to new conditions and requirements i.e. changes in organic waste composition and quantities, climatic conditions, system upgrade among others.

Sources; Researcher, Stakeholders, (Lennartsson 2009; Van Buuren 2010; Andersson et al. 2016a)

Once the key indicators were defined, technical feasibility assessment of the system alternatives proposed for **UCU** was carried out based on qualitative input from the stakeholders already mentioned. Using informant interviews and questionnaires, feedback regarding the technical feasibility of the sanitation system alternatives was elicited from technical staff at the engineering-planning unit, engineering-sanitation lecturers at **UCU** and from experts. Table 7-5 gives a summary of the technical feasibility assessment results for the respective sanitation system alternatives.

Table 7-5: Technical Feasibility Assessment of Sanitation System Alternatives

Parameters	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Robustness						
Sensitivity of sanitation system to shock loads	Low	Medium	Medium	Medium	Medium	Medium
Risk of sanitation system failure	Low	Medium	Medium	Medium	High	High
Complexity of Sanitation System						
Possibility to utilise locally available material and labor for construction of sanitation system	High	High	High	Medium	Medium	Medium
Possibility to utilise locally available labor for operation & maintenance of sanitation system	High	High	High	High	Medium	Medium
Flexibility						
Adaptability of sanitation system to new conditions and requirements	High	Medium	Medium	Low	Low	Low
Average Performance	**1**	**2.1**	**1.6**	**3.8**	**9.5**	**9.5**

Source: Author, based on system evaluation from key informants and experts.

Scale of Average performance; 1 represents good performance and 10 represents poor performance.

7.4.8 Discussion of Results

With reference to the indicators considered, the average performance trend of sanitation system alternatives proposed for **UCU** showed that; the **Status Quo** alternative registered the best performance followed by **COMPAD LF**, **COMPAD, INCAD** while the **INTEG 1** and **INTEG 2** alternatives registered the same value, as summarised in Table 7-5. The overall average low technical feasibility of **INTEG 1** and **INTEG 2** alternatives was attributed to the high risk of system failure and low adaptability anticipated for the sanitation systems. For both **INTEG 1** and **INTEG 2** alternatives, anaerobic digestion of all organic waste was proposed prior to other additional processes such as solar drying and briquette making. As such, failure in the anaerobic digestion process would affect other proceeding processes, exposing the alternatives to high risk of system failure. For other system alternatives which considered parallel processes such as composting or incineration and anaerobic digestion, the potential of system failure in any of the processes was assumed not to directly affect the processes running in parallel. This explains the better performance of the **INCAD, COMPAD**, **COMPAD LF and Status Quo** alternatives in comparison to **INTEG 1** and **INTEG 2**.

Regarding system adaptability, a similar explanation to that of risk of system failure holds. For the alternatives **INCAD**, **COMPAD** and **COMPAD LF,** a higher level of adaptability of the systems is considered achievable in comparison to **INTEG 1** and **INTEG 2**. With reference to this, an example could be that anaerobic digestion of a portion of sewage sludge with cow dung and food waste can additionally be considered for the **INCAD, COMPAD** and **COMPAD LF** alternatives**.** Concurrently, composting or incinerating of sewage sludge with organic or medical waste in the **COMPAD**, **COMPAD LF** and **INCAD** respectively can be accomplished. Thus, the system alternatives can be adapted for adjustment of waste streams managed in addition to the possibility of system improvement or expansion and process optimisation. On the other hand, for the **INTEG 1** and **INTEG 2** alternatives, the opportunity for system adaptability could probably be more towards process optimisation and improvement of efficiency of existing components but not to the sanitation system as whole. Examples of process optimisation could include adjustment in organic loading rate of substrates fed into the anaerobic digester, modification of digester temperatures conditions from mesophilic to thermophilic etc. (refer to Chapter 6). Moreover, the opportunity for system expansion could probably be considered for specific system components such as solar drying or briquetting units. The **Status Quo** alternative on the other hand is considered highly adaptable since it represents the existing sanitation management situation at **UCU,** which offers opportunities for improvement represented by other alternatives.

Notwithstanding the registered good performance of the **Status Quo** alternative, it is crucial that no prejudice is developed towards other system alternatives i.e. **COMPAD**, **COMPAD LF, INCAD, INTEG 1** and **INTEG 2** based on the technical feasibility assessment results. As such, an appreciation of the strengths(S), weaknesses (W), opportunities (O) and threats (T) of the alternatives would enable clear visualisation of the system alternatives. Thus, a **SWOT** analysis was carried out for the sanitation system alternatives.

7.5 Strengths, Weaknesses, Opportunities, Threats (SWOT) Analysis

A **SWOT** analysis basically helps to evaluate the strengths, weaknesses, opportunities and threats involved in any particular project, business enterprise or in this case a sanitation system. Thus, in so doing, a **SWOT** analysis can enable one gain insights into the past and also guide thinking regarding possible solutions to existing or potential problems, either for an existing business/project or for a new venture (Houben et al. 1999; Team FME 2011).

In this research, the **SWOT** analysis is used to enable clear visualisation of the system alternatives suggested for **UCU**. This was mainly carried out to avoid the development of prejudice at an early stage towards the system alternatives which performed poorly in comparison to the **Status Quo** alternative with reference to technical feasibility assessment findings. Thus, identification of strengths, weaknesses, opportunities and threats associated with the respective sanitation system alternatives, which were clustered in three main groups was carried out. The three groups included; **Status Quo**, which registered good overall performance, **COMPAD LF, COMPAD** and **INCAD** alternatives which registered good-medium overall performance and **finally INTEG 1** and **INTEG 2** which registered poor overall performance with respect to technical feasibility assessment (refer to Table 7-5). The **SWOT** analysis was mainly carried out by the researcher and the process was informed by detailed literature review and response from stakeholders who participated in the technical feasibility assessment. Considering that the main objectives of the sanitation system alternatives were to manage organic waste and additionally recover resources, simplified **SWOT** matrices for the sanitation system groups' were generated. Table 7-6 gives a summary of the **SWOT** for the **Status Quo** alternative.

Table 7-6: SWOT Analysis for the Status Quo alternative

Strengths	Weaknesses
• Management of organic waste • System is currently functional thus, necessary know how exists	• Separate management of organic waste streams still practiced, which could imply additional logistical requirements/costs • Challenge experienced in final management of sewage sludge • Negligible resource recovery from organic waste management
Opportunities	**Threats**
• Possibility for further management of sewage sludge • Possibility for system upgrade to incorporate integrated organic waste management rather than a separate management approach • Opportunities for significant resource recovery from management of organic waste	• Failure to manage sewage sludge could pose a public health challenge for **UCU** and thus**,** could have other additional impacts i.e. cost implications or even closure of institution in worst case scenarios

Source: Author

The **Status Quo** alternative which is currently operational, manages organic waste generated from **UCU** separately and this could result in additional logistical requirements, especially with respect to sewage sludge. In case of further treatment/management of the sewage sludge, one of the options could be transportation of the partially stabilised sewage sludge to designated plants such as Lubigi or Bugolobi centralised WWTP, where further management of sewage and faceal sludge are currently carried out. However, considering this option would imply that logistical challenges related to transporting the sludge to these locations which are 22km away from the University would put a strain on the University. Moreover, since the sewage sludge from lagoons has a total solid (TS) content of only 11%, increased sludge volumes due to presence of water as well as odour and aesthetic challenges would be experienced during transportation of such a sludge product, influencing additional costs requirements.

Currently, only about 30% of stabilised sewage sludge from the lagoons at **UCU** is used as soil conditioner or as fertilizer by local farmers and the University thus, resource recovery from this system alternative is negligible. This implies that the additional objective to ensure resource recovery from management of organic waste streams is not really achieved. Based on such a background, opportunities exist for further management of sewage sludge and upgrading of the current system to incorporate an integrated management approach while additionally resulting in significant resource recovery. Moreover, the main threat to the **Status Quo** alternative is that failure to manage the sewage sludge currently left in the lagoons could result in public health related impacts. Such impacts could have negative multiplier effects on the population at **UCU** and could result in closure of the institution in the worst case scenario.

Alternately, a **SWOT** analysis carried out for the **COMPAD LF**, **COMPAD** and **INCAD** alternatives highlights key points summarised in Table 7-7.

Table 7-7: SWOT Analysis for the COMPAD LF, COMPAD and INCAD Alternatives

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>
• Potential for integrated management of organic waste streams from University exists.
• Significant recovery of resources i.e. biogas, compost and organic fertilizer from digestate.
• Possibility for technologies/system processes to run concurrently-i.e. composting and anaerobic digestion or incineration and anaerobic digestion. Thus, a level of flexibility is attached to systems.
• Results in lower or avoided costs that would be incurred in further management of sewage sludge at external facilities (Lubigi, Bugolobi WWTP).
• Could result in additional permanent jobs.
• By additionally managing sewage sludge while recovering biogas, systems contribute to reduction in greenhouse gas emissions.
</td><td>
• Additional requirement for skilled manpower/labour to construct, operate and manage systems.
• Lack of specific national regulations to guide and check quality of biosolids (compost, digestate) generated from systems, prior to application as organic fertilizer.
• Involvement of additional actors through the system value chain could be a cumbersome venture if not well planned.
</td></tr>
<tr><th>Opportunities</th><th>Threats</th></tr>
<tr><td>
• Opportunities for source separation of waste at the University can be further exploited.
• Successful application of system alternatives would promote the proposed integrated sanitation system approach for urban areas in the country.
• A more involved and participatory approach to sanitation could be promoted.
• Research in topic areas related to sanitation system alternatives can be carried out at the University.
• The positive environmental and renewable energy benefits from the sanitation systems create opportunities to receive funding i.e. from Ministry of Energy or grants for example under the auspices of CDM projects.
• Also, opportunities for sanitation system acceptance exist once political backing is involved.
• Moreover, the possibility for system process optimisation to boost performance also exists.
</td><td>
• Acceptance of the system by users i.e. UCU is extremely crucial.
• Skilled labour to ensure operation and management of systems is an important factor.
• Failure in the operation of a particular component e.g. anaerobic digester, composting plant or incinerator may reduce overall system performance.
• Clear definition of roles/responsibilities of various actors and coordination is extremely crucial for successful application of the system alternatives.
</td></tr>
</table>

Source: Author

With reference to the **COMPAD LF**, **COMPAD** and **INCAD** system alternatives, key strengths can be cited in promoting of an integrated organic waste management approach, which results in significant resource recovery in the form of biogas, compost, and digestate. Recovery of biogas from the management of organic waste streams also means that greenhouse gases which would otherwise be emitted to the environment are reduced. In addition, the technology combinations considered for the respective system alternatives allow for concurrent operations i.e. anaerobic digestion process operates independent of composting or incineration processes. By considering any of these alternatives, additional costs required for further management of sewage sludge at other **WWTPs** i.e. Lubigi and Bugolobi would be avoided. Furthermore, additional jobs would be created along the wider sanitation system service chain of the proposed alternatives.

Some of the key weaknesses associated with these system alternatives include additional requirement for skilled manpower to construct, operate and maintained the systems. Furthermore, bearing in mind that multiple actors and or stakeholders would be involved and that utilisation of organic fertilizer from system processes is proposed, institutional and regulatory framework requirements should be catered for.

Numerous opportunities can be cited for the system alternatives as highlighted in Table 7-7. Overall, successful application of the system alternatives would promote possible implementation of an integrated sanitation system approach, which additionally incorporates a participatory approach. This implies that demand based sanitation systems would be planned for and implemented by various stakeholder groups (EAWAG-SANDEC 2005; Lüthi et al. 2011a; Parkinson et al. 2014). Application of demand based sanitation systems can be guaranteed to last longer once stakeholder views are incorporated and their respective involvement is well defined or structured (further discussion in Chapter 10). Moreover, further research in related topic areas of incineration, composting and anaerobic digestion among others could be pursued at the University, informing system operation and maintenance. The fact that the sanitation systems result in resource recovery in the form of energy and nutrients also implies that funding opportunities to support such projects can be obtained from government entities or organisations with similar interests. Possibilities to obtain funding under the auspices of clean development mechanism (CDM projects), Ministry of Energy- Renewable Energy Department are some of the cited opportunities (MEMD 2012; CDM 2009). Obtaining political backing for such sanitation systems would give the necessary boost for further implementation within the country.

In spite of the strengths and opportunities cited with regards to these sanitation system alternatives, acceptance of the systems by the users (**UCU**) is crucial to implementation. Bearing in mind that a participatory approach is adopted, no consent from the potential system users would be a major threat to possible system implementation. Moreover, acceptance of sanitation systems is often dependent on socio-cultural aspects, which are influenced by the various backgrounds of the users (Schelwald and Reijerkerk 2009; Drangert 2004; Kvarnström et al. 2004).

Also, the absence of necessary skilled manpower to operate and manage the sanitation systems would be a major hindrance to the successful implementation of the systems. The mere fact that involvement of numerous actors or stakeholder groups is anticipated also calls for proper definition of roles or responsibilities if successful implementation of the sanitation systems is to be achieved (refer to Chapter 10).

With regards to the sanitation system alternatives **INTEG1** and **INTEG 2**, a similar discussion as for **COMPAD LF**, **COMPAD** and **INCAD** alternatives holds with a few additional exceptions. In terms of strengths, **INTEG 1** and **INTEG 2** alternatives additionally consider utilisation of wastewater effluent as process water for the anaerobic digestion process, while briquettes would be additionally recovered from digestate. Particularly in terms of threats to the sanitation system alternatives, the performance to these systems is dependent on the anaerobic digestion process. Thus, any failure in operation of the anaerobic digestion unit would significantly affect the entire system as already highlighted.

The **SWOT** analysis carried out for the sanitation system alternatives highlights the fact that resource recovery from organic waste management is a crucial component. For the **Status Quo** alternative which registers negligible resource recovery, the related system strengths and opportunities were also limited. While for all the other alternatives which considered significant resource recovery (**COMPAD LF, COMPAD, INCAD, INTEG 1 and INTEG 2**), additional opportunities and system strengths were cited. In addition, for the alternatives which considered significant resource recovery, capitalisation on their respective strengths and opportunities could counteract some of the cited weaknesses and threats. For instance, the sanitation system weaknesses related to requirement of skilled labor in addition to institutional and regulatory framework requirements could be countered by exploiting opportunities for related research and promoting a participatory approach. Moreover, by considering a participatory approach, local authorities, interested organisations and government entities would be involved at an early stage of the process and this would go a long way in boosting the sanitation system performance.

Therefore, even though the technical feasibility assessment findings discussed in Section 7.4.8 showed that the **Status Quo** alternative performed better than other sanitation system alternatives, the **SWOT** analysis brings these sanitation systems to the "spotlight" as well. By exposing the strengths, weaknesses, opportunities and threats associated with **COMPAD LF, COMPAD, INCAD, INTEG 1**and **INTEG 2** alternatives, the **SWOT** analysis illuminates how attractive these alternatives are while giving an overview of each system.

Generally, with reference to the integrated sanitation system approach suggested in this research, it is prudent that the system objectives are clearly stipulated. This would enable a clear visualisation of the broad picture of the sanitation systems irrespective of the tools used for assessment of technical feasibility. As already highlighted, the objectives of the integrated sanitation systems include management of organic waste streams and resources recovery.

Thus, appreciation of the broader perspective of the systems would imply both objectives are reflected in the assessment. To accomplish such a task, supporting tools such as **SWOT** analysis may be useful in portraying the full picture of the sanitation systems. This could check decisions making based on early prejudice of sanitation systems from initial assessments, which could result in premature elimination of the. Moreover, the fact that a holistic feasibility assessment approach is considered further implies that preliminary elimination of sanitation system alternatives can be avoided since the feasibility assessment of other additional aspects for each of the system alternatives is taken into account. Carrying out a **SWOT** analysis in addition to other methods used for technical feasibility assessment may particularly be necessary in cases where upgrading of existing or conventional systems to integrated sanitation systems is considered. However, in cases where there is an opportunity to install a new sanitation system, then **SWOT** analyses may not be required to justify consideration of various alternatives. Moreover, this also highlights the fact that experts in sanitation such as engineers, planners etc. should be involved at the preliminary stages of system planning and design to ensure informed assessment of system alternatives.

In conclusion, this Chapter discusses the principles and factors enabling the design of integrated sanitation system alternatives. With information from the initiation phase of the research in combination with the principles of sanitation service delivery and influencing factors, six sanitation system alternatives were designed and proposed for **UCU.** A technical feasibility assessment of the sanitation system alternatives was then carried out and the results showed that the **Status Quo** alternative performed better than the remaining five alternatives, which considered the integrated sanitation system approach**.** To avoid early prejudice towards the other system alternatives, a **SWOT** analysis was carried out to further inform the technical feasibility assessment. The analysis showed that integrated sanitation system alternatives were equally attractive, especially due to the resource recovery potential attached to the systems.

Given that a holistic feasibility assessment approach is adopted in this research, assessment of the environmental feasibility of the sanitation system alternatives was carried out and a detailed discussion included in Chapter 8 of this dissertation.

8 Environmental Feasibility Assessment of Sanitation System Alternatives Proposed for UCU

Chapter 8 *examines the environmental feasibility of the sanitation system alternatives proposed for* ***UCU*** *using Life Cycle Assessment (LCA). The environmental performance of the sanitation system alternatives is determined by assessing the potential environmental impacts of each system with reference to the resources used and recovered. The Chapter then concludes with a sensitivity analysis.*

8.1 LCA for UCU

In this Chapter, the environmental feasibility assessment of the six sanitation system alternatives proposed for **UCU** was carried using the **LCA** methodology already described in Chapter 5 of this dissertation. With reference to the phases of **LCA** methodology framework, discussion of the main phases of the **LCA** for **UCU** follows.

8.1.1 Goal and Scope Definition

The overall goal of this **LCA** was to assess the environmental performance of the sanitation system alternatives proposed for **UCU.** In so doing, the environmental burden or impacts associated with management of the organic waste streams and resource recovery from the specific sanitation systems was investigated. The **LCA** considered only the operation stage of the sanitation systems proposed for **UCU**. This decision was based on the discourse in most **LCA** studies, which points out that the environmental impacts from replacement of equipment and construction of facilities are lower in comparison to the environmental burden from the operational stage. This discourse especially holds when systems assessed are proposed to have a long lifetime of at least 25 years (Emmerson et al. 1995; Pillay 2006; Remy 2010). The **LCA** was performed using Gabi 6 professional software, which enables life cycle assessments to support design for the environment, eco-efficiency, eco-design and efficient value chains. The software has been applied to carry out **LCA`s** in various fields supporting academia, professionals as well as industrial sectors (Gabi 2011).

8.1.1.1 Sanitation System Boundaries

The key components of the ***Status Quo*** alternative boundary consisted of pumping sewage sludge from the **WWTP** to gravity settling tank and partial stabilisation of sewage sludge in lagoon. Also, application of 30% of partially stabilised sewage sludge as conditioner and dumping of 70% of residual sewage sludge was considered. Other considerations in this system boundary included; food waste (**Fw**) from the kitchen was used as animal feed and cow dung (**Cd)** applied in gardens/dumped in animal kraal.

The ***COMPAD*** alternative boundary consisted of pumping sewage sludge from **WWTP** to the gravity settling tank and partial stabilisation of sewage sludge in the lagoon. Thereafter, co-composting of sewage sludge from the lagoon with other organic waste was considered and the compost generated would be utilised as soil conditioner.

Furthermore, the pretreatment of **Fw** and mixing with **Cd** prior to anaerobic co-digestion of **Cd:Fw 30:70** was considered. Utilisation of biogas that would be produced from the anaerobic digestion process was examined in two scenarios i.e. direct utilisation as cooking fuel (**BfC**) or for cogeneration (**CoGen**) of electricity and heat from the **CHP** unit. Meanwhile, the application of digestate that would be generated from the anaerobic digestion process as organic fertilizer was included within the boundary. Therefore, substitution of electricity from the national grid, thermal energy generated from firewood for cooking and mineral fertilizers are included in the **COMPAD** boundary.

*The **COMPAD LF*** alternative boundary was similar to the **COMPAD** with the exception that the co-composting process would be carried out at Mukono Municipal landfill instead of at **UCU** campus. Thus, transportation of stabilised sewage sludge to the landfill which is located about 7km away from the University campus was included within the boundary.

*The **INCAD*** alternative boundary consisted of similar components to the **COMPAD** alternative with the exception of drying the partially stabilised sewage sludge from the lagoon prior to co-incineration with other waste streams.

*The **INTEG 1*** alternative boundary consisted of pumping of sewage sludge from the **WWTP** and dewatering of sewage sludge in gravity settling tank. Pretreatment of **Fw** prior to mixing with **Cd** and dewatered sewage sludge (**Os)** was also included in the boundary. Thereafter, anaerobic digestion of the substrate mixture **Os: Cd: Fw 30:20:50** was taken into account and utilisation of biogas generated would be accomplished in similar manner to **COMPAD, COMPAD LF** and **INCAD** alternatives. Partial stabilisation of the digestate in the lagoon prior to solar drying and application as organic fertilizer was additionally considered for **INTEG 1** alternative. The substitution of firewood, grid electricity and mineral fertilizer production processes were also included in **INTEG 1** system boundary.

*The **INTEG 2*** alternative boundary was similar to **INTEG 1** alternative and additionally considered faecal sludge (**Fs**) as one of the substrates that would be anaerobically digested. Thus, a substrate mixture of composition **Fs:Os:Cd:Fw 10:20:20:50** was considered. Furthermore, **INTEG 2** alternative boundary included utilisation of 40% solar dried digestate for briquette making while 60% of leftover dried digestate was considered for use as organic fertilizer. The substituted processes considered for **INTEG2** alternative were similar to those considered for **INTEG 1** alternative with the inclusion of substitution of firewood with briquettes made from digestate. For all the system alternatives which consisted of the anaerobic digestion process, heat generated from the cogeneration (**CoGen**) scenario was considered for heating water, which would later be utilised for cooking purposes. For all the sanitation system boundaries defined, reference is made to Figure 7-1 to Figure 7-6 for the respective systems included in Chapter 7 of this dissertation.

8.1.1.2 Assumptions and Limitations

The following assumptions and limitations were considered when carrying out this **LCA**.

Assumptions

1. Organic waste streams were considered as inputs to the sanitation systems and not followed upstream.
2. Wastewater treatment was not considered however, the management of generated sludge i.e. pumping and dewatering was included in system boundaries.
3. System boundaries were expanded to include processes for generation or production of substituted implements i.e. electricity, thermal energy and mineral fertilizer.
4. The sanitation system boundaries did not include: construction of system components, vehicles, machines and auxiliary equipment required for sanitation systems. This assumption was based on findings from various **LCA** studies, which suggest that for technical systems with a long life, environmental impacts associated with the operation stage were more significant and this justified the delimitation in this **LCA** (Emmerson et al. 1995; Pillay 2006; Remy 2010).
5. The system boundaries did not include transportation of faecal sludge (**Fs)** from source points since it was assumed that **Fs** would be collected from various locations within Mukono Municipality. Thus, transportation of the faecal sludge would be the responsibility of interested parties (customers)**.** Similarly**,** transportation of partially stabilised sludge/digestate considered for use as conditioner or organic fertilizer by interested customers was not included in system boundaries. The assumption was based on the understanding that interested customers would collect and deliver the conditioner/organic fertilizer to various locations where it is required.
6. For **COMPAD, COMPAD LF, INCAD, INTEG 1** and **INTEG 2** alternatives, two scenarios for utilisation of biogas from the anaerobic digestion process were considered; either the biogas was used directly as cooking fuel (**BfC**) or for the cogeneration of electricity and heat from the **CHP** unit. The heat from the cogeneration process was further considered for heating water, which would be used for cooking purposes.
7. In the **BfC** scenario, thermal energy generated from biogas was credited by subtracting the thermal energy generated when firewood was used for cooking purposes. Alternately, electricity generated from the **CHP** unit was credited by subtracting electricity from grid mix system. While the heat produced from the **CHP** unit was credited by subtracting an equivalent amount of thermal energy generated from firewood.
8. The stabilised sewage sludge from the lagoon used as soil conditioner and the digestate produced from the anaerobic digestion process were credited by subtracting mineral fertilizer modeled as Nitrogen, phosphorus and potassium(NPK) 15-15-15 mineral fertilizer in Gabi 6 software.

9. The calorific value of digestate (with at least 70% **TS**) was assumed to be 15MJ/kg based on literature (Shirani and Evans 2012; Kratzeisen et al. 2010).
10. Biogas leakages/emissions from the anaerobic digestion plant could occur at various points which may include the CHP unit, gas storage unit, along the piping and within the digestate storage unit. Studies have shown that biogas emissions from a biogas plant could range between 3-7% of biogas generated although emissions from the digestate storage unit could vary between 0.2%-11% of biogas generated (Jonerholm and Lundborg 2012; Jørgensen, and Kvist 2015; Flesch et al. 2011). The wide variation with regards to emissions from the digestate unit is mainly because about 15% of biogas generation is estimated to take place at the digestate storage unit. In cases where the digestate storage unit is not covered, significant emissions from the digestate unit can be expected (Liebetrau et al. 2013). Therefore, for all the sanitation alternatives which consisted of the anaerobic digestion process, emissions from the unit were assumed to be 7% of the biogas generated.

Limitation

1. For electricity and diesel processes used in the Gabi 6 software models, Norway mixed grid electricity and India diesel mix were applied respectively. Since Gabi 6 software does not have process data from Uganda let alone the African region, Norway electricity grid mix and diesel mix from India was considered representative of the Ugandan scenario. The Norway electricity grid mix was mainly dependent of hydropower, accounting for at least 95% of overall electricity in the grid mix as at 2012, which was the reference duration of the data set (Gonzalez et al. 2011). While India being a middle income country, the diesel refinery process was considered roughly similar to the situation in Uganda.

   The electricity grid mix from India could not be used since it's the main contribution was from coal, accounting for at least 57% of overall mix. While the electricity mix for Uganda showed that hydro power accounted for at least 87% of all electricity in the grid (Mudoko 2013). Given that technological variations at the power generation plants i.e. emission control measures from generator sets etc. could vary in the Norwegian setting in comparison to Uganda, the absence of regional (Africa) specific data in Gabi 6 Software was considered a limitation to the **LCA**.

8.1.1.3 Functional Unit (FU)

The functional unit basically measures performance of the functional outputs of the product system. The main purpose of the functional unit is to provide a reference to which the inputs and outputs can be related (ISO 1997; Jensen et al. 1997). This enables the comparison of different systems providing the same service which is the case in this **LCA**. Essentially, the main goal of any sanitation system is to ensure improved management/disposal of waste streams (wastewater, solid waste etc.).

In this research, the main goal of the sanitation system alternatives proposed for **UCU** is to ensure improved management of organic waste generated from the University (sewage sludge, cow dung and kitchen waste) and neighboring Mukono area (faecal sludge). Therefore, the **FU** applied in this **LCA** was the management of **897 tonnes** of organic waste by the sanitation system alternatives proposed. The **FU** corresponded to the amount of organic waste generated annually.

8.1.2 Life Cycle Inventory

The inventory phase involved data collection and calculation procedures for quantification of relevant inputs and outputs of the sanitation system alternatives with reference to the **FU**. Thus, computation of the raw materials that would be consumed, energy used and potential emissions to environment for all sanitation system alternatives was carried out.
Locally, data was compiled from **UCU** and this included information on sewage sludge pumping from the **WWTP**, quantities of organic waste generated, distances covered in case of waste transportation etc. Additional relevant data from available literature, publications and government documents were also obtained. Application of information obtained from secondary sources was considered with reference to the assumptions made. Furthermore, additional data for processes such as electricity grid mix, thermal energy from firewood, mineral fertilizer production, transportation, incineration and landfill processes was obtained from GaBi 6 Professional database.

Noteworthy is that information on substrate composition used for the different sanitation system alternatives was based on experimental analysis discussed in Chapter 6. Also, during the inventory computation, the potential CO_2 emitted during the utilisation of firewood for cooking was counted as biogenic. This implied that CO_2 emitted from these processes was considered to have zero impact to climate as suggested by IPCC guidelines (IPCC 2006; EPA 2011). Besides, the upstream processes related to collection and transportation of firewood were not included in the system boundaries thus, inclusion in the inventory was not considered. Table 8-1 and Table 8-2 show the inventory data for emissions from electricity and artificial fertilizer production as well as other unit processes. Moreover, the inputs, outputs and emissions computed for respective sanitation systems alternatives are also included in Table 8-3.

Table 8-1: Inventory Data for Emissions from Electricity

Mixed Grid electricity (Norway)	Flows	Amount	Units (kWh^{-1})
Emissions to Air			
Inorganic emissions to air	Water Vapor	7.04	kg
	CO_2	0.0453	kg
	CO	0.0349	g
	NOx	0.0502	g
	SO_2	0.0215	g
Organic emissions			
	CH_4	0.0386	g
	Hydro carbons unspecified	0.0133	mg
Emissions to fresh water			
Analytical measured	AOX	0.144	mg
	BOD	0.0646	mg
	COD	0.0149	g
Inorganic emissions to	Ammonia	0.0934	mg
	Nitrate	7.77	mg
	Nitrite	0.0178	mg

Source; (Gabi 6 database Thinkstep 2012)

Table 8-2: Inventory Data for Emissions from Artificial Fertilizer Production

NPK 15-15-15	Flows	Amount	Units (kg^{-1})
Emissions to Air			
Inorganic emissions	CO_2	0.844	kg
	Ammonia	0. 0235	g
	NOx	1.05	g
	SO_2	0. 369	g
	Fluoride	0. 833	g
	Dust (>PM10)	0. 0362	g
	Water vapour	3.13	kg
Organic emissions			
	CH_4	2.96	g
	Hydro carbons unspecified	0. 00979	g
Emissions to Fresh water			
	Ammonia	0. 751	mg
	Sulphate	0. 526	g
	Nitrite	0. 502	g
Heavy metal emissions to air	Manganese	0.137	mg
	Chromium	0. 00419	mg

Source: (Gabi 6 database Thinkstep 2012)

Table 8-3: Summary of Inventory Data for the Sanitation System Alternatives

Waste treatment	Flow	Amount Status Quo	Amount COMPAD	Amount COMPAD LF	Amount INCAD	Amount INTEG 1	Amount INTEG 2	Units (per ton of waste)	Source
Sludge pumping									
Energy consumption	Electricity	0.203	0.203	0.203	0.203	0.203	0.203	kWh	Calculated
Composting									
	N		0.55	0.55				kg	Literature [a]
	P_2O_5		1.9	1.9				kg	Literature
	K_2O		6.4	6.4				kg	Literature
Landfilling									
Gaseous emissions	CH_4	0.0294			-	-	-	kg	Calculated
	NO_x	0.248			-	-	-	g	Gabi database
	CO	1.04			-	-		g	Gabi database
	NMVOC (non- methane volatile organic carbons)	0.015			-	-	-	g	Gabi database
Incineration									Gabi database
Gaseous emissions	CO_2		-		0.629	-	-	Kg	Gabi database
	Exhaust		-		3.42	-	-	Kg	Gabi database
	NO_x		-		0.297	-	-	g	Gabi database
	NMVOC		-		1.47	-	-	mg	Gabi database
	Slag		-		0.607	-	-	kg	Gabi database
Pretreatment									
Energy consumption	Electricity		1.289	1.289	1.289	1.289	1.289	kWh	Calculated
Water	Fresh water		1693.2	1693.2	1693.2			L	Calculated
	Effluent(process H_2O)		-		-	361.3	484.3	L	Calculated
Anaerobic Digestion									
Energy consumption	Electricity		34	34	34	34	34	kWh	Literature [b]
Waste production	Digestate		1404.7	1404.7	1404.7	1606.74	2527	kg/day	Calculated
Valuable materials	Biogas		263.6	263.6	263.6	350.6	493.4	Nm^3/day	Calculated

	CH_4		60	60	60	60	60	%	Literature [b]
	CO_2		40	40	40	40	40	%	Literature [b]
Gaseous Leakages	Biogas		10	10	10	10	10	%	Estimated
Lagoon-digestate									
Valuable materials	NPK fertilizer		17.05	17.05	9.89	4.64	4.03	kg	Estimated
	Briquettes						378.5	kg	Calculated
Combined Heat & Power(CHP) unit									
Material Consumption	Lubricating Oil		0.01	0.01	0.01	0.01	0.01	kg	Literature [b]
Gaseous emissions	CO		0.4	0.4	0.4	0.4	0.4	kg	Literature [b]
	NO		0.3	0.3	0.3	0.3	0.3	kg	Literature
	NMVOC		0.3	0.3	0.3	0.3	0.3	kg	Literature
	SO_2		0.01	0.01	0.01	0.01	0.01	kg	Literature
Valuable materials	Electricity		441.3	441.3	441.3	587	826	kWh/day	Calculated
	Thermal energy		740.2	740.2	740.2	984.7	1385.5	kWh/day	Calculated
Firewood as cooking fuel(1kg) [c]	Emissions								
	CO_2		1.70	1.70	1.70	1.70	1.70	kg	Literature
	CH_4		0.42	0.42	0.42	0.42	0.42	m^3	Estimated-[d]

Sources: a (Wrap 2016), b (Righi et al. 2013), c (IPCC 2006), d (IRENA 2016)

Note: For all calculated values in Table 8-3, necessary computations were based on 1 tone of organic waste although the input values modeled in Gabi 6. Software were computed with reference to the functional unit.

8.1.3 Life Cycle Impact Assessment (LCIA)

Identification and evaluation of the emission amounts and significance of the potential environmental impacts arising from the life cycle inventory was carried out in **LCIA** phase. Prior to modeling of the inventory data for computation of potential impacts, impact categories were assigned for the inputs and outputs. As such, classification and characterisation which are mandatory steps within this phase were carried out (ISO 1997; Gabi 2011). The **CML 2001** methodology included within Gabi 6 software already factored in classification and characterisation steps. Other optional steps such as normalisation and weighting were not considered in this **LCA** (Gabi 2011).

Taking into account that no agreed universal list of impact categories exists, the following set was selected; global warming (**GWP**), acidification (**AP**), eutrophication (**EP)**, photochemical ozone creation potential (**POCP**) and Human toxicity potential (**HTP**). The choice of the impact categories was influenced by the anticipated impacts from improper management of the organic waste streams considered i.e. sewage sludge, animal excreta, organic waste and wastewater effluent as already highlighted in Chapter 3. Thus, impacts related to eutrophication of water bodies and acidification of the environment can be anticipated in case untreated organic waste is improperly discharged into the environment (Lüthi et al. 2011b; ECA 2016).

Meanwhile, emissions associated with generation of electricity and combustion of diesel resources which are used for operating various processes during the management of organic waste streams could also contribute to acidification and eutrophication potentials. Moreover, methane emissions from the degradation of organic waste streams contribute to global warming and ozone depletion potential. In addition, emission of heavy metals to water bodies and soil can also be anticipated in case of improper sewage sludge treatment/disposal and these emissions can be reflected by human toxicity potential (Gabi 2011; Metcalf and Eddy 2004). Therefore, the potential environmental impacts associated with the management of organic waste streams generated annually from **UCU** and neighbouring environments were represented by the impact categories selected. Besides, similar impact categories have been used in environmental assessments of sanitation system related **LCAs** (Remy 2010; Righi et al. 2013; Chiu et al. 2016). In addition, the choice of the impact categories was also influenced by Gabi 6 professional software, which has a list of about 11 impact categories to choose from.

8.2 LCA Results

The results from computation of the environmental impact for the six sanitation system alternatives are summarised in Table 8-4 while Figure 8-1 and 8-2 display process contributions to the respective impact categories by specific sanitation system alternatives. Overall, the main processes included in the system boundaries were summarised as; dumping of partially stabilised sewage sludge from lagoon (**LDS**), combination of solar drying of partially stabilised sewage sludge and incineration (L**IN**), co-composting of partially stabilised sludge (**LCP**) and solar drying of digestate from the lagoon (**LSD**).

Moreover, other processes considered include; pretreatment of substrate(**PT**), anaerobic digestion (**AD**), fertilizer substitution (**FS**), utilisation of firewood for cooking (**UFc**), substitution of firewood with biogas for cooking (**FBgS**), substitution of firewood with briquettes for cooking (**FBqS**), combined heat and power unit (**CHP**) for cogeneration of heat and electricity.

As already highlighted in the assumptions considered**,** for all alternatives which included the anaerobic digestion process, utilisation of biogas produced was based on two scenarios i.e.; direct utilisation of biogas directly for cooking purposes (**BfC**) or cogeneration (**CoGen**) of electricity and heat from the **CHP** unit. Hence, computation of the impacts included both scenarios as shown in Table 8-4.

Table 8-4: Environmental impact for sanitation system alternatives with reference to the FU

Impact category	Units	Status Quo	COMPAD		COMPAD LF		INCAD		INTEG 1		INTEG 2	
			BfC	CoGen	BfC	CoGen	BfC	CoGen	BfC	CoGen	BfC	CoGen
GWP	kg CO_2 eq	3.27E+05	4.18E+04	4.36E+04	4.16E+04	4.33E+04	1.35E+05	1.35E+05	3.93E+04	4.04E+04	4.47E+04	4.45E+04
AP	kg SO_2 eq	5.28E+02	4.48E+02	5.29E+02	4.48E+02	5.29E+02	3.67E+02	4.04E+02	4.96E+02	5.48E+02	2.35E+02	2.46E+02
EP	kg PO_4^{-3}eq	2.58E+02	6.83E+01	8.18E+01	6.83E+01	8.18E+01	8.28E+01	8.96E+01	7.71E+01	8.63E+01	3.58E+01	3.88E+01
POCP	kg Etheneeq	1.44E+02	7.42E+01	9.49E+01	7.39E+01	9.47E+01	7.49E+01	8.90E+01	7.10E+01	7.60E+01	4.02E+01	5.12E+01
HTP	kg DCB eq	1.71E+04	1.45E+04	1.68E+04	1.45E+04	1.68E+04	1.30E+04	1.38E+04	1.57E+04	1.69E+04	7.56E+03	7.50E+03

Source; Gabi 6 Software

The results from the **LCA** highlight the environmental burdens or impacts associated with the management of **897 tonnes** of organic waste streams by each of the sanitation system alternatives suggested for **UCU**. With regards to this **LCA**, positive results depict a load to the environment or resource use, while negative values show savings or recovery. Savings occur when avoided burdens are larger than impacts associated with the waste treatment process. Thus, a negative value indicates an environmental benefit and the positive one specifies an environmental burden. Moreover, with reference to the various impact categories, registering of lower impact values was preferred since this implied lower environmental burden.

The results shown in Table 8-4 indicated that when **BfC** scenario was considered, all sanitation system alternatives performed better than **Status Quo** for all impact categories by registering lower impact values than those of the **Status Quo** alternative. When the **CoGen** scenario was considered**,** the **COMPAD, COMPAD LF and INTEG 1** alternatives registered slightly higher values for **AP** than the **Status Quo** alternative. Moreover, a negligible variation in results ranging between 0.03-0.02 kg CO_2 eq for **GWP** and 0.20 kg Ethene eq for **POCP** with respect to the **COMPAD** and **COMPAD LF** alternatives was registered. The negligible difference in **GWP** and **POCP** results for the **COMPAD** or **COMPAD LF** alternatives implied that either of the system alternatives could be opted for in case the **CoGen** scenario was considered.

The specific performance of the sanitation system alternatives varied as is further discussed in latter sections. Except for the **INCAD** alternative where a similar **GWP** result for both **BfC** and **CoGen** scenarios was registered, all other sanitation system alternatives which consisted of anaerobic digestion process showed higher impact values for **CoGen** in comparison to **BfC** scenario (refer to Table 8-4).

8.2.1 Global Warming Potential (GWP)

The **Status Quo** alternative registered the highest **GWP** value followed by **INCAD, INTEG 2, COMPAD, COMPAD LF** while **INTEG 1** alternative performed best. Dumping of residual sewage sludge from the lagoon mainly contributed to the **GWP** from the **Status Quo** alternative and this process accounted for up to 97% of the methane (**CH_4**) emissions. For the remaining sanitation system alternatives, the trend of performance for **COMPAD/COMPAD LF** and **INTEG 1** when both **BfC** and **CoGen** scenarios were considered indicated that the most dominant processes contributing to the **GWP** were anaerobic digestion (**AD**), accounting for at least 68% the overall **GWP** and utilisation of firewood for cooking (**UFc**) contributing 20.8% to the **GWP**. The anaerobic digestion process emitted mainly **CH_4** gas while **CO_2** was emitted from utilisation of firewood as cooking fuel.

With reference to the **INTEG 2** alternative, anaerobic digestion and utilisation of firewood for cooking processes dominantly contributed to **GWP.** In addition, the briquette making process accounted for 14% the total **GWP**. For the **INCAD** alternative, co-incineration of sewage sludge and waste process contributed 60% to overall **GWP** while utilisation of firewood for cooking contributed 12% to total **GWP**.

The significant contribution of anaerobic digestion process to **GWP** with reference to **COMPAD, COMPAD LF, INCAD, INTEG 1** and **INTEG 2** alternatives was partly attributed to biogas leakages as fugitive emissions. This was particularly the case for CH_4 emissions, which have a **GWP** up to 28 times CO_2 equivalent for 100 year time horizon (IPCC 2006). Figure 8-1and Figure 8-2 show process contribution to the **GWP** for the respective sanitation system alternatives.

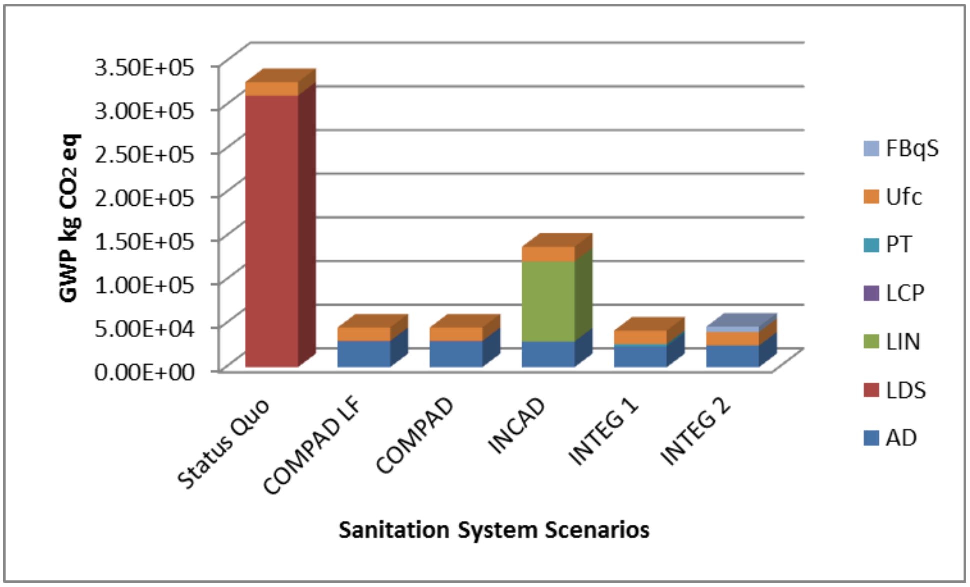

Figure 8-1: BfC Scenario showing process contribution to GWP
Source; Gabi 6 Software

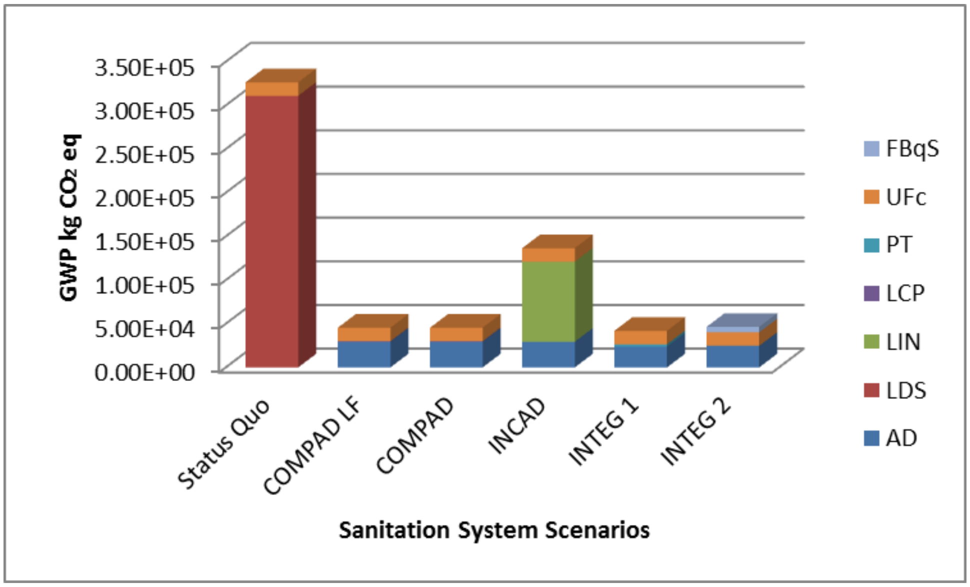

Figure 8-2: CoGen scenario showing process contribution to GWP
Source; Gabi 6 Software

Although the overall **GWP** was positive (load to environment), significant reduction in substances contributing to the **GWP** were noted. For the respective sanitation system alternatives, significant reduction in **GWP** was attained from utilisation of biogas as a cooking fuel instead of wood fuel and this accounted for a reduction of upto**-1340 kg CO_2 eq**. While the substitution of artificial fertilizer with organic fertilizer from digestate and compost resulted in reduction in the **GWP** of at least **-1210 kg CO_2 eq.** Energy recovery from the **CHP** unit in the form of heat and electric power accounted for modest reduction in the **GWP** of at least **-178 kg CO_2 eq.** Table 8-5 shows a summary of process contribution to reduction in the **GWP** for the respective sanitation system alternatives.

Table 8-5: Process Contribution to Reduction in GWP for Sanitation System Alternatives

Scenarios	COMPAD /INCAD BfC	COMPAD/ INCAD CoGen	INTEG 1 BfC	INTEG 1 CoGen	INTEG 2 BfC	INTEG 2 CoGen
Fertilizer (kg CO_2 eq)	-1.27E+03	-1.27E+03	-1.21E+03	-1.21E+03	-1.54E+03	-1.54E+03
Thermal energy (kg CO_2 eq)	-2.36E+03	-3.76E+02	-1.34E+03	-1.78E+02	-2.06E+02	-2.86E+02
Power(kg CO_2 eq)		-2.18E+02		-1.03E+02		-1.66E+02
Total savings (kg CO_2 eq)	-3.63E+03	-1.86E+03	-2.55E+03	-1.49E+03	-1.75E+03	-1.99E+03

Source: Gabi 6 Software

8.2.2 Acidification Potential (AP)

The trend of performance with reference to **AP** showed that **INTEG 2** alternative had the least value followed by the **INCAD**, **COMPAD**, **INTEG 1** and finally the **Status Quo** when the **BfC** scenario was considered. When the **CoGen** scenario was taken into account, the **INTEG 2** and **INCAD** alternatives still performed better than the **Status Quo** alternative while the **COMPAD** and **INTEG 1** alternatives registered **0.01** and **0.20 kg SO_2 eq** higher than the **Status Quo** respectively**.** For all alternatives, the most dominant process accounting for up to 100% of the **AP** was the utilisation of firewood for cooking purposes. With reference to the **Status Quo** alternative, utilisation of firewood for cooking process emitted Sulphurdioxide **SO_2** (34%), nitrogen oxides **NO_x** (37%), hydrogen chloride gas **HCl** (13%). While the same process emitted mainly **NO_x** (40%), **SO_2** (38%) for **COMPAD, COMPAD LF, INCAD INTEG 1** and **INTEG2** alternatives.

A reduction in substances resulting in **AP** was noted mainly when the **BfC** scenario was considered. The most significant reduction was registered for the **INTEG 2** alternative due to the additional utilisation of briquettes instead of firewood for cooking. The reduced emissions contributing to **AP** from briquette use contributed to the significant reduction.

Moreover, modest cut backs in substances contributing to **AP** were also registered from the incineration process where inbuilt emission control measures reduce the emission of flue gases such as **SO_2** and **NOx,** which would otherwise contribute to **AP** (Knospe and Walleser 2004; Brent 2006). Table 8-6 gives a summary of process contribution to the reduction in **AP** for specific sanitation system alternatives.

Table 8-6: Process Contribution to Reduction in AP for Sanitation System Alternatives

Scenarios	COMPAD BfC	INCAD BfC	INCAD CoGen	INTEG 1 BfC	INTEG 2 BfC
Thermal energy (kg SO_2 eq)	-8.10E+01	-8.10E+01		-4.59E+01	-7.06E+00
Thermal energy (kg SO2 eq)briquettes					-2.86E+02
Process recovery(kg SO_2 eq		-1.25E+02	-1.25E+02		
Total savings (Kg SO_2 eq)	-8.10E+01	-2.06E+02	-1.25E+02	-4.59E+01	-3.87E+02

Source; Gabi 6 Software

8.2.3 Eutrophication Potential (EP)

The trend of performance with reference to **EP** indicated that **INTEG 2** alternative registered the least value followed by **COMPAD, INTEG 1**, **INCAD** and finally **Status Quo** alternative. The main processes which contributed to the **EP** with reference to the **Status Quo** alternative were dumping of the partially stabilised sewage sludge, accounting for 69% and utilisation of firewood for cooking which contributed 31% to total **EP**. The main discharge to the environment from dumping of sewage sludge included ammonia **NH_3** (68%) to soil while utilisation of firewood for cooking emitted mainly **NO_x** (19%) and **NH_3** (6%) to air. With reference to **COMPAD, INCAD, INTEG 1** and **INTEG 2** alternatives, utilisation of firewood for cooking accounted for atleast 90% **EP** and emitted mainly **NO_X.**

The most significant reduction in substances contributing to lower **EP** was registered by substitution of firewood for cooking with briquettes and biogas, which was noted mainly for the **INTEG 2, COMPAD** and **INCAD** alternatives. Briquettes utilisation accounted for up to **-43.5kg PO_4^{-3} eq** reduction while utilisation of biogas for cooking accounted for **-12.3kg PO_4^{-3} eq** reduction in the **EP.**

8.2.4 Photochemical Ozone Creation Potential (POCP)

The **INTEG 2** alternative performed best followed by the **INTEG 1**, **INCAD**, **COMPAD LF**, **COMPAD** and finally the **Status Quo** with regards to **POCP**. For the **Status Quo** alternative, utilisation of firewood accounting for 56% **POCP** and dumping of the partially stabilised sewage sludge contributing 44% to total **POCP,** were the most dominant processes. Carbonmonoxide **CO** (29%), **NO_x** (7%) were mainly emitted from firewood utilisation process while dumping of stabilised sewage sludge emitted non-methane volatile organic compounds **NMVOC** (38.2%). For the remaining sanitation system alternatives, when the **BfC** scenario was considered, the most dominant process accounting for up to 100% of the **POCP** was firewood utilisation for cooking. When the **CoGen** scenario was considered, the same process was dominant and contributed at least 80% to **POCP** while anaerobic digestion and the **CHP** unit processes additionally contributed 7% and about 8% respectively. The main emission from utilisation of firewood in the **CoGen** scenario were **NMVOC** accounting for (40%), **CO** (34%), **NO_x** (14%) and **SO_2** (10%) while the anaerobic digestion process emitted at least 7% of **CH_4** emissions contributing to the **POCP.**

The most significant reduction in substances contributing to **POCP** was registered by substitution of firewood utilisation with briquettes and biogas. Since burning briquettes results in reduced amounts of gaseous emissions contributing to **POCP**, substitution of firewood with briquettes and biogas was significant, particularly with regards the **INTEG 2** alternative (Pilusa et al. 2013). While for **COMPAD**, **INCAD** alternatives, reduction in the **POCP** was mainly due to substitution of firewood used with biogas. Substitution of firewood with briquettes accounted for up to **-44kg Ethene eq** reduction while biogas utilisation for cooking accounted for -**12.3 kg Ethene eq** reduction in **POCP** mainly for the **COMPAD** and **INCAD** alternatives**.** The **INTEG 1** alternative also registered minimal reduction of up to **-7kg Ethene eq** in **POCP** from the substitution of firewood with biogas**.**

8.2.5 Human Toxicity Potential (HTP)

The trend of performance with reference to **HTP** was similar to that of **AP,** where **INTEG 2** alternative registered the least value followed by **INCAD**, **COMPAD**, **INTEG 1** and finally **Status Quo**. For all the alternatives, utilisation of firewood for cooking purposes dominantly accounted for at least 90% **HTP** when both **CoGen & BfC** scenarios were considered. The main emission to air from this process was hydrogen fluoride gas (**HF**).
Significant reduction in substances contributing to **HTP** was registered mainly from briquette and biogas utilisation instead of firewood for cooking purposes. Moreover, due to the emission control measures incorporated in the incineration process, significant reduction in substances contributing to **HTP** was also registered for the **INCAD** alternative. Thus, **INTEG 2** and **INCAD** alternatives showed significant reduction of at least **-9.68E+03 kg DCB eq** and -**3.44E+03 kg DCB eq** in **HTP** respectively. Table 8-7 gives a summary of process contribution to reduction in **HTP** for the specific sanitation system alternatives.

Table 8-7: Process Contribution to Reduction in HTP for Sanitation System Alternatives

Scenarios	COMPAD BfC	COMPAD CoGen	INCAD BfC	INCAD CoGen	INTEG 1 BfC	INTEG 1 CoGen	INTEG 2 BfC	INTEG 2 CoGen
Fertilizer (kg DCB eq)	-1.78E+01	-1.78E+01	-1.78E+01	-1.78E+01	-1.58E+01	-1.58E+01	-2.01E+01	-2.01E+01
Power (k DCB eq)								
Thermal energy (kg DCB eq)	-2.63E+03	-3.91E+02	-2.75E+03	4.19E+02	-1.49E+03	-1.99E+02	-2.29E+02	-3.18E+02
Process (kg Ethene eq)			-3.00E+03	-3.00E+03				
Thermal energy (kg DCB eq)briquettes							-9.34E+03	-9.34E+03
Total savings (kg DCB eq)	-2.65E+03	-3.99E-02	-5.77E+03	-3.44E+03	-1.51E+03	-2.15E-02	-9.58E+03	-9.68E+03

Source: Gabi 6 Software

8.2.6 Discussion of Results

The discussion in this section helps in identifying which of the proposed sanitation systems result in the lowest environmental burdens. In so doing, hot-spots for which further improvement with regards to the sanitation systems are identified. The results from the **LCIA** indicated that all sanitation system alternatives which considered a combination of anaerobic digestion and other processes performed better than the **Status Quo** alternative, especially when the **BfC** scenario was considered**.** An exception was noted when the **CoGen** scenario was considered with reference to the **COMPAD** and **INTEG 1** alternatives, which registered slightly higher values than the **Status Quo** alternative for Acidification potential **(AP).** In general, the results indicated better environmental performance for all sanitation system alternatives which additionally consisted of the anaerobic digestion process in comparison to the **Status Quo** alternative. These results concurred with other comparative **LCA** studies for sewage sludge and organic waste management, which indicated that application of anaerobic digestion for management of the organic waste streams improved environmental performance due to resource recovery in the form of energy and nutrients (Righi et al. 2013; Chiu et al. 2016).

Furthermore, the results showed that for all sanitation system alternatives which consisted of the anaerobic digestion process, the **BfC** scenario performed better than the **CoGen** scenario. This suggested that utilisation of **BfC** was considered more environmentally friendly than utilisation of biogas for **CoGen**. However, a decision in favor of this suggestion would be dependent on the priorities of **UCU** i.e. whether substitution of firewood with biogas for cooking purposes would be a more urgent requirement than own electricity generation for running other processes within the University.

Overall, variable performance of the sanitation system alternatives with the exception of **Status Quo** was registered. Slight variations in the range of 0.03-0.02 kg CO_2 eq for the **GWP** and up to 0.20 kg Ethene eq for the **POCP** from **COMPAD LF** and **COMPAD** alternatives were registered. These variations in values were considered insignificant and also suggested that either **COMPAD** or **COMPAD LF** alternatives could be considered in case a choice between the two alternatives was to be made.

The trends of performance of specific impact categories such as **GWP** showed variations i.e. **INTEG 1>COMPAD LF>COMPAD>INTEG 2>INCAD>Status Quo.** With reference to the **AP and HTP** impact categories**,** the performance trend showed **INTEG 2 >INCAD> COMPAD/COMPAD LF >INTEG 1>Status Quo.** The trend of performance for the **EP** impact category was **INTEG 2 >COMPAD/COMPAD LF> INTEG 1 >INCAD>Status Quo.** While the performance trend for the **POCP** impact was **INTEG 2 >INTEG 1 >INCAD >COMPAD LF>COMPAD>Status Quo.**

The most dominant processes which contributed to **GWP** were anaerobic digestion contributing at least 61% and utilisation of firewood as cooking fuel contributing up to 37% to **GWP** for all sanitation system alternatives except the **Status Quo** alternative. Moreover, other specific processes such as, dumping of partially stabilised sewage sludge contributed up to 97%, incineration up to 68% and briquette making contributed 14% to the **GWP** with reference to the **Status Quo**, **INCAD** and **INTEG 2** alternatives respectively. Utilisation of firewood for cooking purposes was the most dominant process contributing at least 90% to **AP**, **EP**, **POCP**, **HTP** impacts for all sanitation system alternatives except **Status Quo.** Specifically for the **Status Quo** alternative**,** dumping of sewage sludge was the most dominant process contributing to **POCP**.

The significant contribution to various impact categories due to firewood utilisation reflected on the dependence on firewood use at **UCU,** which accounted for about 90% cooking energy demand. Important to note was that fugitive emissions from the biogas digestion process accounted for at least 80% of the **GHGs** from the anaerobic digestion process. The significant contribution to **GHGs** from fugitive emissions was attributed to the initial assumptions made, where fugitive emissions from the proposed anaerobic digestion plant accounted for up to 7% of the biogas generated.

Resource recovery from specific sanitation system alternatives contributed to the variation in environmental performance. Resource recovery processes which included; substitution of firewood with biogas and, or briquettes for cooking purposes, substitution of electricity from national grid with electricity generated from the **CHP** unit and substitution of mineral fertilizer with compost or organic fertilizer from digestate, directly contributed to impact reduction and overall performance of system alternatives. As far as avoided impacts due to resource recovery were concerned, substitution of firewood for cooking with biogas was quite significant for all impact categories. Impact reduction from mineral fertilizer substitution with compost or organic fertilizer utilisation was also significant and registered at least **-1270 kg CO_2 eq** for all five alternatives with reference to **GWP.**

Significant reduction in substances contributing to **AP** and **HTP** impacts were also registered when firewood utilisation was substituted by briquette use with reference to the **INTEG 2** alternative. This was because utilisation of briquettes for cooking resulted in minimal amounts of emissions contributing to **AP** and **HTP** (Pilusa et al. 2013). Furthermore, emission control measures incorporated in the incineration process also accounted for the significant reduction in substances contributing to **AP** and **HTP** impacts with reference to the **INCAD** alternative. For both sanitation system alternatives, significant reduction in **AP** of at least **-2.06E+02 kg SO_2 eq** and **-3.44E+03 kg DCB eq** with reference to **HTP** were registered (refer Table 8-6 and Table 8-7).

Taking into consideration all impact categories, the assessment of environmental performance for the system alternatives indicated that the **INTEG 2** alternative performed best followed by the **COMPAD LF**, then **COMPAD**, **INTEG 1**, **INCAD** and finally the **Status Quo** alternative in that order**.** The trend of performance clearly showed that all other alternatives which consisted of a combination of anaerobic digestion and other processes performed better than the **Status Quo** alternative, which represents the current sanitation system at **UCU.** This implied that with reference to management of organic waste streams generated annually, consideration of any of these alternatives would result in less environmental burden in comparison to the current sanitation system at **UCU.** Moreover, the results showed a direct correlation between resource recovery and environmental performance as justified by the overall good performance of the **INTEG 2** alternative.

The avoided emissions due to substitution of firewood use with biogas and briquettes made from digestate contributed to the overall good performance of the **INTEG 2** alternative. Overall, these results concur with findings from other **LCA** studies which suggest that avoided emissions due to resource recovery result in improved environmental performance of systems (Parkes et al. 2015; Righi et al. 2013)**.** Particularly with reference to the **INTEG 2** alternative, additional resource recovery reflected by utilisation of briquettes made from digestate as cooking fuel contributed to improved performance (lower impact) of the alternative. These results also concurred with findings by (Kratzeisen et al. 2010), who suggested that utilisation of dried digestate as a fuel was an attractive venture for biogas plants.

Moreover, Pilusa et al. (2013) in their study also determined that emissions from eco-briquettes were minimal and conformed to the *Occupational Safety and Health Agency* (OSHA) exposure standards. Besides, the good performance of the **INTEG 2** alternative also justified the current discourse, which emphasises the importance of post treatment measures in improvement of digestate utilisation (King and Bardos 2013; Al Seadi et al. 2008; Drosg et al. 2015). There is no doubt that financial implications related to post treatment measures can be expected to increase hence, the decision on the viable measures for post treatment of digestate should be based on the priorities of **UCU.**

Al Seadi and Lukehurst (2012) clearly point out that in consideration of digestate and stabilised sewage sludge as organic fertilizer or soil conditioner, health risks due to exposure to pathogens and contamination by heavy metals are issues of concern. As already mentioned in Chapter 6, tests for heavy metal content in the sewage sludge obtained from the lagoons at **UCU** showed compliance with **EPA** standards and **EU** directives for biosolid application on land (refer to Appendix 4 for test results). Furthermore, while designing the sanitation system alternatives, the risk of exposure to pathogens were incorporated. Thus, processes such as solar drying of digestate and sewages sludge in addition to co-composting as well as storage of compost and digestate over durations of time were included(refer to Chapter 7).

Noteworthy was that transportation and distribution of organic fertilizer, particularly for the **COMPAD, COMPAD LF, INTEG 1 INTEG 2** and **INCAD** alternatives could result in additional energy demand in comparison to when mineral fertilizer is used. This is because the organic fertilizer produced could vary in composition as a result of post treatment/handling measures thus, more quantities of organic fertilizer may be required to obtain similar mineral fertilizer content (UNITO 2014). Therefore, further research to validate the environmental impacts related to transportation and application of organic fertilizer would be necessary although this is beyond the scope of this **LCA**. Having identified the hot spots with reference to the various sanitation system alternatives, a sensitivity analysis was carried out to understand how the overall results of a selected system alternative would be affected by changes in certain assumptions.

8.2.7 Sensitivity Analysis

Taking into consideration that the **LCA** was carried out based on assumptions initially described in Section 8.1.1.2, it was only prudent to assess the influence of changes in these assumptions on the environmental performance of the sanitation system alternatives. From the results discussed, it was clear that the anaerobic digestion and utilisation of firewood for cooking processes among others significantly contributed to the overall environmental performance of the sanitation system alternatives. Thus, to fully appreciate the influence of these processes, a sensitivity analysis which included variation of fugitive emissions and amount of firewood substituted was carried out.

Scenario 1

INTEG 2 alternative was selected for the sensitivity analysis because the alternative clearly reflected the direct correlation between resource recovery and environmental performance. The baseline conditions initially considered the worst case scenario of fugitive emissions (biogas leakage) i.e. 7% of biogas generated from the. For the sensitivity analysis, a reduction in fugitive emissions to 5% and later 3% was considered with reference to experiences from biogas plant operations mainly in Europe (Jonerholm and Lundborg 2012; Jørgensen and Kvist 2015).

Computation of the environmental impact for the **INTEG 2** alternative resulted in a significant reduction in **GWP** of up to 27% when the fugitive emissions were reduced to 5%. While only a 15% reduction in the **GWP** was registered when fugitive emissions were further reduced from 5% to 3%. Consecutively, a 7% and 3% reduction in **POCP** for the respective 5 % and 3% reduction in fugitive emissions was registered. While minimal reductions of 0.1%were noted for other impact categories as summarised in Table 8-8.

Table 8-8: Sensitivity Analysis Results based on Reduction of Fugitive Emissions

Impact Category	Units	Baseline (7%) fugitive emissions	Scenario 1(5%) fugitive emissions	Scenario 2 (3%) fugitive emissions
GWP	kg CO_2 eq	4.47E+04	3.26E+04 ↓	2.78E+04 ↓
AP	kg SO_2 eq	2.35E+02	2.34E+02	2.34E+02
EP	kg PO_4^{-3} eq	3.58E+01	3.57E+01	3.57E+01
POCP	kg Ethene eq	4.02E+01	3.74E+01 ↓	3.62E+01 ↓
HTP	kg DCB eq	7.56E+03	7.55E+03	7.54E+03

Source: Gabi 6 Software Where ↓ implies significant decrease in impact

Scenario 2

Furthermore, substitution of firewood used for cooking with biogas and variation of the substituted amounts over the range -20%, to 20% was considered. Substitution of firewood with biogas for cooking by 10% and 20% resulted in an overall sensitivity of less than 3% and 5% respectively for all impact categories. With reference to specific impact categories, 20% substitution of firewood with biogas resulted in sensitivity value for **GWP** of 5.2%, **POCP** 6.6%%, **HTP** 7.9%. While **AP** and **EP** impacts registered 7.8% sensitivity. Table 8-9 Shows the results of the impact categories for various adjustments considered.

Table 8-9: Substitution of Firewood with Biogas for Cooking - INTEG 2 Alternative

Impact Category	Unit	-20% & TBgS	-10% TBgS	Baseline	10% TBgS	20% & TBgS
GWP	kg CO_2 eq	4.34E+04	4.32E+04	4.30E+04	4.28E+04	4.26E+04
AP	kg SO_2 eq	1.87E+02	1.81E+02	1.74E+02	1.67E+02	1.60E+02
EP	kg PO_4^{-3} eq	2.86E+01	2.76E+01	2.66E+01	2.55E+01	245E+01
POCP	kg Ethene eq	3.31E+01	3.21E+01	3.11E+01	3.00E+01	2.90E+01
HTP	kg DCB eq	6.03E+03	5.81E+03	-5.59E+03	-5.37E+03	5.15E+03

Source; Gabi 6 Software

Scenario 3

Finally, substitution of firewood with briquettes for cooking by 10% resulted in sensitivity of 107% for **GWP**, 160% for **AP**, 162% for **EP**, 153% for **HTP** and over 1000% for **POCP**. While substitution of firewood with briquettes by 20% resulted in sensitivity of 214% for **GWP**, 321% for **AP**, 325% for **EP**, 306% for **HTP** and over 2000%. The results indicated that substitution of firewood with briquettes significantly influenced **POCP** in comparison to **GWP**. A summary of the sensitivity analysis results for the specific impact categories is shown in Table 8-10.

Table 8-10: Substitution of Firewood with Briquettes for Cooking- INTEG 2

Impact Category	Unit	-20% & TBqS	-10% TBqS	Baseline	10% TBqS	20% & TBqS
GWP	kg CO_2 eq	4.02E+04	3.85E+04	3.69E+04	3.52E+04	3.36E+04
AP	kg SO_2 eq	7.8E+01	2.14E+01	-3.55E+01	-9.23E+01	-1.49E+02
EP	kg PO_4^{-3} eq	1.19E+01	3.32E+01	-5.33E+00	-1.40E+00	-2.26E+01
POCP	kg Ethene eq	1.65E+01	7.91E+0	-0.72E+00	-9.34E+00	1.80E+01
HTP	kg DCB eq	2.48E+03	6.41E+02	-1.20E+03	-3.075+03	-4.89E+03

Source; Gabi 6 Software

Overall, the sensitivity analysis results showed that substitution of firewood with briquettes for cooking purposes registered the highest sensitivity values in comparison to substitution of firewood with biogas and reduction of fugitive emissions. The trend of performance is explained by the fact that reduced emissions contributing to respective impact categories result from utilisation of briquettes. As such, variation in amounts of briquettes used can be easily reflected in the impact categories results. These sensitivity results also concur with the discussion in Section 8.2.6**,** which highlighted the influence of briquette utilisation on the overall environmental performance of **INTEG 2**. Moreover, the sensitivity analysis further illuminated the importance of; substitution of firewood with cleaner cooking fuel sources and reduction of fugitive emissions from the biogas plant. Other sensitivity analyses could also be carried out such as efficiency and substitution rates on the overall results for the avoided impacts. However, this is beyond the scope of this study.

8.3 Conclusion

The environmental feasibility assessment of the sanitation system alternatives proposed for **UCU** was carried out using **LCA**. The goal of the **LCA** was to assess the environmental burden/impact associated with the management of organic waste streams generated annually from **UCU** and neighboring areas of Mukono Municipality. Gabi 6.0 professional Thinkstep sustainability software was used to enable the computation of the environmental impact.

The results indicated that all sanitation system alternatives which combined anaerobic digestion and other processes for the management of organic waste performed better than the **Status Quo** alternative, which represents the current sanitation system at **UCU**. This basically suggests that the integrated sanitation systems proposed for **UCU** would result in less environmental burden in comparison to the current sanitation system when similar amount of organic waste is managed. The results also showed that either the **COMPAD or COMPAD LF** alternatives could be considered since variation in the respective environmental burden between the two alternatives was insignificant**.**

Variation in the performance trends was noted for certain impact categories. Thus, for **GWP,** the trend of performance was **INTEG 1**>**COMPAD LF**>**COMPAD**>**INTEG 2**>**INCAD>Status Quo.** For **AP and HTP** impacts**,** the performance trend showed **INTEG 2** >**INCAD> COMPAD/COMAPD LF** >**INTEG 1>Status Quo. For EP** impact the trend of performance was **INTEG 2** >**COMPAD/COMPAD LF**> **INTEG 1** >**INCAD>Status Quo.** While **POCP** impact performance indicated **INTEG 2** >**INTEG 1** >**INCAD** >**COMPAD/COMPAD LF>Status Quo.** The overall environmental performance trend for the sanitation system alternatives was **INTEG 2 > COMPAD LF >COMPAD>INTEG 1> INCAD** > **Status Quo.** The good performance of **INTEG 2** alternative in comparison to other alternatives was attributed to the significant resource recovery associated with additional utilisation of briquettes made from digestate for cooking purposes.

With reference to process contribution to the environmental impacts, anaerobic digestion accounting for 61% and utilisation of firewood as cooking fuel accounting for 37% were the most dominant processes contributing to **GWP**. Moreover, specific processes like dumping of partially stabilised sewage sludge accounted for 97%, incineration 68% and briquette making 14% to **GWP** with reference to **Status Quo**, **INCAD** and **INTEG 2** alternatives respectively. While for the remaining impact categories i.e. **AP**, **EP**, **POCP**, **HTP**, the most dominant process was utilisation of firewood for cooking, which contributed to at least 90% the respective impact categories. The dominant contribution of firewood utilisation to the environmental burden highlighted the heavy dependence of **UCU** on firewood for cooking, which accounted for 90% of fuel used for cooking purposes and was included in the system designs. Based on these findings, it is evident that the twofold objectives for the integrated sanitation systems proposed i.e.; *management of organic waste streams and resource recovery* can be concurrently achieved and this would contribute to reduced environmental burden from respective sanitation systems.

A sensitivity analysis carried out showed that reduction in fugitive emissions by 5% resulted in significant reduction for **GWP** up to 27%. However, further reduction of fugitive emissions to 3% resulted in only a 15% reduction in **GWP.** Consecutively, a 7% and 3% reduction in **POCP** were registered when fugitive emissions were reduced to 5% and 3% respectively. Substitution of firewood with biogas for cooking purposes showed an overall sensitivity of at least 5% for all impact categories. While similar substitution of firewood with briquettes resulted in higher sensitivity of at least 200% for **GWP**, **AP**, **EP**, **HTP** and over 2000%for **POCP.** The sensitivity analysis highlighted importance of; substitution of firewood with cleaner cooking fuel sources and the reduction of fugitive emissions from the biogas plant.

Noteworthy is that the **LCA** results suffice for the specific boundaries and scope conditions considered. Thus, further research to validate the environmental impacts related to the application of the digestate on soil in addition to determining the energy demand related to transportation and application of digestate and compost among others would probably illuminate areas for further improvements.

Given that resource recovery is an additional objective for integrated sanitation systems, considering these systems for housing estates, institutions, peri-urban and towns/cities implies that an overall better environmental performance can be expected. Moreover, a positive correlation exists between the environmental performance of the sanitation systems and resource recovery. The more resources are recovered, the better the sanitation system is expected to perform.

With reference to resource recovery in the form of biogas, further reduction in particularly global warming and photochemical ozone creation potentials for integrated sanitation systems can be ensured when additional measures to limit biogas leakage are considered. Biogas leakages amounting to at most 3% would imply further reduction in the environmental impacts mentioned from the sanitation systems. Moreover, the replacement of other unclean energy sources such as firewood or charcoal use with biogas or briquettes produced from the integrated sanitation systems would also result in reduced environmental impact from the systems. Substitution of conventional firewood use with biogas and or briquettes from digestate contributes to significant environmental savings due to avoided greenhouse gas (**GHG**) emissions.

The findings from the **LCA** for **UCU** also illuminate certain key aspects that can be generally considered in case of environmental assessment of integrated sanitation systems. Firstly, a clear break down or definition of the integrated sanitation system goal would be necessary to further inform the assessment. For instance, understanding the mode of recovered resource utilisation is crucial. *Is the biogas recovered used directing for cooking purposes or for cogeneration. What are the expectations from digestate as a resource recovered? Is the digestate required more as organic fertilizer and in which form i.e liquid or solid form. Can the digestate be used as fuel source*? Appreciation of such information in addition to clear definition of other processes considered in the sanitation system would be crucial since it influences the overall performance of specific sanitation systems once modeled in **LCA** supporting tools or software. In line with this suggestion, biogas for cooking could be considered a priority for institutions of learning, which in most cases depend on firewood for cooking. Meanwhile, biogas for cogeneration of electricity and heat could be considered for hospitals, housing estates, peri-urban areas, town and city integrated sanitation systems, where the requirement for electricity may be a priority. Also, institutions of learning that have additional land may prefer to use the digestate on their farms without further processing or post treatment. On one hand, in case the produced digestate is desired by interested farmers as fertilizer, then a much more portable byproduct may be preferred. Thus, further processing of the digestate may be necessary. On the other hand, briquettes made from digestate may also be preferred at institutions, in housing estates and by interested farmers, influencing the digestate post treatment measures considered.

Important to note is that the absence of representative datasets can be a main limitation to **LCAs** and this has to be taken into consideration. For instance, most **LCA** soft wares do not have Africa regional datasets as such, during modeling of systems, data sets for specific processes used may be those considered to be relatively close to the regional conditions.

This limitation can inherently influence the results of an **LCA** since in most cases data sets from developed countries are used. Often the case, the data sets from developed countries incorporate the most recent /modern technologies, which could additionally include emission mitigation measures. Once such data sets are used for modeling sanitation systems used in Africa for instance, they may not reflect the actual situation in terms of emissions to the environment and this could influence the overall **LCA** result. An ideal scenario would be to use tools/software that have regional specific data or at least data sets such as electricity mix and other specific processes which are considered much more reflective of the regional conditions. Such a scenario may be possible in the future and as such variation in **LCA** results can be expected.

Having assessed the environmental feasibility of the sanitation system alternatives using **LCA,** the economic feasibility assessment of the system alternatives was carried and is discussed in Chapter 9 of this dissertation.

9 Economic Feasibility Assessment of Sanitation System Alternatives

Chapter 9 *examines the economic feasibility of the sanitation system alternatives proposed for **UCU** using a cost benefit analysis approach. The assessment was accomplished by additionally computing the net present value, internal rate of return and the payback period for the respective sanitation system alternatives. The Chapter concludes with a sensitivity analysis for selected system alternatives.*

9.1 Economic Feasibility Assessment

The economic feasibility assessment of the sanitation system alternatives is carried out with reference to the cost benefit analysis approach (**CBA**) while additionally incorporating parameters such as the net present value (**NPV**), payback period (**PBP**) and internal rate of return (**IRR**). Apart from incorporating all system component installation and operation costs, the business case of the sanitation systems is argued based on the economic returns associated with reducing the burden on health, environmental issues as well as citizens' lost time and productivity (WSP 2008; McIntyre et al. 2014; TBC 2016). Moreover, returns, associated with potential resource recovery from management of the various organic waste streams are additionally considered.

9.2 Assessment of Sanitation System Alternatives for UCU

The **NPV** is the sum of all cash flows discounted for the given duration thus, the time value of money is recognised using **NPV**, which is computed according the Equation9-1;

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad \text{……………………………………………………Equation 9-1}$$

Where **NPV** is the net present value of the sanitation system (s), $\mathbf{C_t}$ is the cash flow of the investment for the duration **t**, $\mathbf{C_0}$ is the initial investment for the sanitation system , **r** is the discount rate (%), **t** is the time period from the first year 1 to **T** years (lifetime of sanitation system).

The **IRR** which is the discount rate when the after-tax **NPV** is zero is computed according to Equation9-2.

$$\mathbf{0 = \sum_{t=1}^{T} C_t\ (1 + IRR)^{-t} - C_0} \text{ ………………………………………………………Equation 9-2}$$

Where IRR is the internal rate of return of the sanitation system (s), $\mathbf{C_t}$ is the cash flow of the investment for the duration **t**, $\mathbf{C_0}$ is the initial investment for the sanitation system, **t** is the time period from the first year 1 to **T** years.

The **PBP** basically compares revenues with costs and determines the duration required to recoup the initial investment of a given project and is computed according to Equation9-3.

$$\mathbf{PBP} = \frac{\textbf{\textit{Initial investment}}}{C_t} \quad \text{..Equation 9-3}$$

Where $\mathbf{C_t}$ is the cash flow of the investment in time period **t** (s) and **PBP** is the payback period

9.2.1 Scope of Sanitation System Alternatives

The economic assessment for the six sanitation system alternatives i.e. **Status Quo**, **COMPAD LF**, **COMAPD**, **INCAD**, **INTEG1**, **and INTEG 2** was executed with reference to scope defined in this section. Key sanitation system process components such as the anaerobic digestion technology, sewage sludge handling and transportation of substrates were considered. Thereafter, monetarisation of the costs for the respective system alternatives was carried out. With reference to the anaerobic digestion process common to all alternatives except the **Status Quo**, key stages were considered and these included; access to substrate, pretreatment of substrate and post treatment of both biogas and digestate among other stages as described.

Access to substrate; with reference to the **UCU** context, food waste and sewage sludge would be obtained from the University kitchen and **WWTP** respectively. Depending on the proposed anaerobic digestion plant location i.e. near the kitchen or at the **WWTP**, transportation of the substrates to these locations was considered negligible. On the other hand, access to cow dung was anticipated from the University farm located about 3.5km from the campus. Thus, daily transportation costs for required amounts of cow dung were taken into consideration. With reference to faecal sludge as a substrate, the proposed collection of faecal sludge from the neighboring areas of Mukono Municipality and its subsequent transportation to the **WWTP** at **UCU** would be catered for by the interested customers.

Pretreatment stage; consisted of substrate storage and sorting in addition to provisions for size reduction, particularly for the food waste. Thus, in addition to substrate storage units, mixing/feeding components were considered for the **COMPAD**, **COMPAD LF**, **INCAD**, **INTEG 1**and **INTEG 2** alternatives.

Anaerobic digestion stage; after pretreatment of the substrate, the substrate mixture would then be anaerobically digested in a continuous stirred tank reactor (**CSTR**) already described in Chapter 6 of this dissertation. The proposed location of the anaerobic digestion plant for the **COMPAD, COMPAD LF** and **INCAD** alternatives was considered to be near the kitchen. While for the **INTEG 1** and **INTEG 2** alternatives, the proposed digester location would be at the **WWTP**.

Handling/post treatment stage; included provisions for biogas scrubbing i.e. reduction of water vapor, carbon dioxide and hydrogen sulphide (H_2S) content in biogas prior to utilisation in cooking burners or the **CHP** unit. Scrubbing of biogas would boost gas burner and **CHP** unit efficiencies (Al Seadi et al. 2008; Zhao et al. 2010). As already highlighted in Chapter 7, post treatment of digestate is important in case improved utilisation of the digestate is envisioned. Hence, for the **COMPAD, COMPAD LF** and **INCAD** alternatives, digestate generated would be recycled into the **CSTR** prior to storage for a period of up to 6 months. Recycling of the digestate and storage for a duration of time would boost further stabilisation since the anaerobic digestion process already contributes to pathogen reduction(Al Seadi and Lukehurst 2012; Al Seadi et al. 2008). The stabilised digestate generated from food waste and cow dung substrate mixture can then be utilised as organic fertilizer by interested customers without the risk of exposure to pathogens. Moreover, for the **COMPAD, COMPAD LF** alternatives, co-composting of partially stabilised sewage sludge from the lagoon with organic waste was considered either at **UCU** or at the composting plant located at Mukono Municipal landfill. As such, the compost generated from these alternatives was considered for use by interested customers.

For the **INTEG 1** and **INTEG 2** alternatives, the digestate produced from anaerobic digestion of cow dung, food waste, sewage sludge and faecal sludge would be partially stabilised in the lagoon over a period of up to 9 months, attaining **TS** of up to 30%. Thereafter, the partially stabilised digestate would then be solar dried to ensure full stabilisation and attaining **TS** of at least 70%. For the **INTEG 1** alternative, the solar dried digestate would then be used as organic fertilizer. While for the **INTEG 2** alternative, 60% of the solar dried digestate would be used as organic fertilizer and the remaining 40% is proposed for briquette making. The briquettes made are then considered for cooking purposes within the University, substituting firewood use.

9.3 Data Sources and Analysis

Data used for the economic assessment of the sanitation system alternatives was obtained from key informants and observation during fieldwork. Additional data relevant to the anaerobic process was obtained through experimental analysis discussed in Chapter 6. Finally, reference to existing literature related to economic feasibility of biogas plants, costing of biogas plants and sanitation systems also enabled relevant cost estimation for the system alternatives considered (Karellas et al. 2010; Pantaleo et al. 2013; Otoo et al. 2015). Comprehensive estimation of costs for the sanitation system components of each sanitation system alternative, taking into consideration the substrate composition, process or technology combinations and the various inputs and outputs was carried out. Thereafter, the potential benefits accrued from utilisation of biogas and digestate were evaluated.

Moreover, environmental benefits such as reduction in **GHGs** and health benefits associated with improved sanitation from the respective system alternatives were additionally included to ensure that the **CBA** was more comprehensive (Ackerman 2008; Weimer 2008).

The environmental benefits were represented by the reduction of **GHGs** for respective sanitation systems and this was further informed by the environmental assessment discussed in previous Chapter. While the health benefits associated with the respective sanitation system alternatives was computed based on guidance from literature, which suggests that waterborne and sanitation related diseases consist mainly of infectious diarrhoea. The disease burden further includes cholera, salmonellosis, shigellosis, amoebiasis, and other protozoal and viral intestinal infections. These diseases are transmitted by water, person-to-person contact, animal-to-human contact, and foodborne, droplet and aerosol routes among others. Infectious diarrhoea causes the main global burden of disease resulting from poor access to water supply and sanitation. Moreover, the availability of regional and national data on diarrhoea incidence rates and deaths has contributed to investigations of the health benefits of sanitation interventions with reference to reduction in diarrhoea incidence (Hutton and Haller 2004; Hutton et al. 2007; Hutton 2012).

In addition, since environmental risk factors are estimated to account for 50% of under nutrition in the developing world, diseases with higher incidence or case fatality due to malnutrition are also included within the disease burden. Some of these diseases include a proportion of cases of respiratory infection and malaria attributed to poor water supply and sanitation, which is based on very severe and moderately severe malnutrition rates especially in the 0-5year age group. Important aspects related to these diseases have been determined by region-specific attribution factors thus, with reference to mortality, the case fatality of respiratory infection, malaria, measles and other infections are affected (Hutton 2012, 2015; Hutton et al. 2007; Lüthi et al. 2011b). Therefore, with reference to such a background, the economic benefits of health impacts associated with improved sanitation services have also been assessed based on three key points suggested in literature (Hutton et al. 2007; Hutton 2012, 2015). A similar stance is applied in this research and three key points considered include;

- Savings related to seeking less health care. Such savings are estimated as a function of treatment seeking rates, medical practices and unit costs of medical services. These medical practices include the types of treatment given for a disease and the rate of in-patient admission or referral. Generally, these variables fluctuate by disease and country. In addition, the patients and their caretakers incur treatment-seeking costs such as travel costs.
- Savings related to productive time losses from disease. The productivity losses are estimated based on disease rates in addition to the number of days absent from productive activities and the unit value of productive time. Taking into account the stringent data requirements to estimate specifically financial losses from lost productive time, the common practice is that an economic value is given based on the sick person's age. Moreover, to promote gender equity, men's and women's time are given the same value.

- Finally, savings related to reductions in premature mortality. Here, mortality is valued using the human capital approach to estimate the value of a premature death averted.

To ensure that no costs or benefits of any specific sanitation systems were left out, reference to specific units or processes within the sanitation systems was considered. For instance with reference to the anaerobic digestion process, a generic model to ease computation of various costs and benefits was proposed and this included; separate management of sewage sludge and, or combined management with other organic waste streams i.e. cow dung, food waste and faecal sludge. Figure 9-1 shows an overview of key processes considered at the anaerobic digestion stage already discussed.

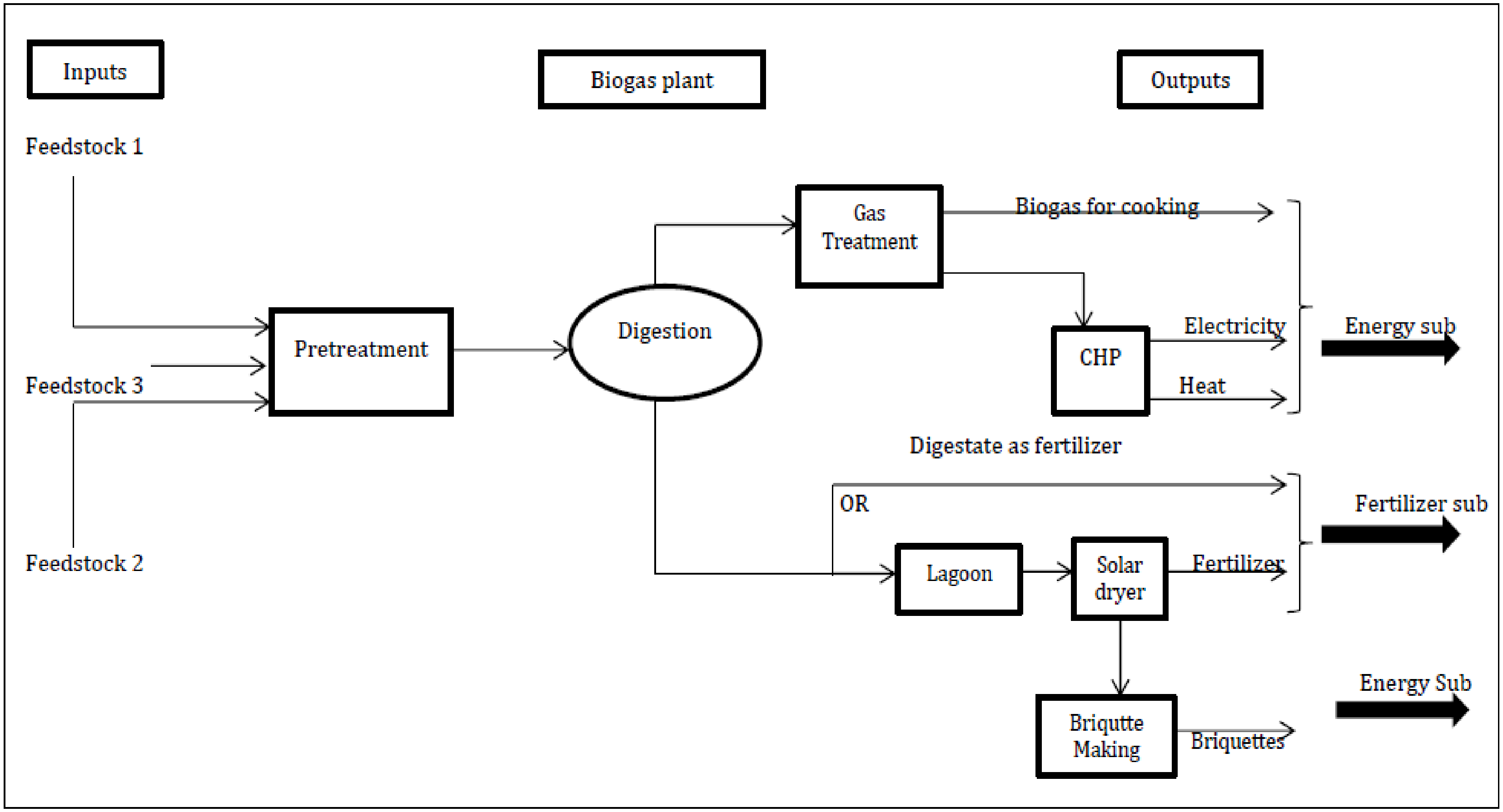

Figure 9-1: Simplified flow diagram of the anaerobic digestion plant component of proposed sanitation system alternatives
Source:Author

A Microsoft Excel tool was developed and used to investigate the economic feasibility of the sanitation system alternatives. At the initial stage, computation of the available substrate quantities was carried out for the anaerobic digestion units, then the annual biogas amounts for the specific system alternatives was determined. Computation of the biogas amounts was based on substrate characteristics i.e. **TS** % and **oTS/VS**% determined through experimental analysis and reference to literature (Al Seadi et al. 2008; Vögeli et al. 2014). Thereafter, other costs and benefits related to the environmental and health aspects of all sanitation systems were also computed. Table 9-1 shows the substrate estimates and the respective characteristics considered for computing the annual biogas amounts from specific system alternatives.

Table 9-1: Summary of Available Substrate/Feedstock

Substrate/feedstock type	Input Tons/year	TS Tons /year	VS Tons/year
Food waste	202.23	53.69	52.30
Cow dung	208.53	36.14	27.66
Sewage Sludge	486.68	10.56	7.81
Faecal sludge	243.34	8.52	6.30

Source: Author

9.4 Economic Feasibility Assessment

The feasibility assessment included examination of the implementation and operation of key components considered for the management of organic waste streams in the respective sanitation system alternatives. Specifically, estimation of the biogas plant capacity was carried out with reference to the estimated biogas quantities from the respective system alternatives. Estimation of the initial investment costs for the sanitation system alternatives was then carried out. The estimation of investment costs was informed by supplier information for various components of the proposed sanitation systems and this information was obtained from **UCU** and other suppliers. In addition, information was obtained from relevant literature related to various process/technology installations suggested in the system alternatives (Walla, Schneeberger 2008; Karellas et al. 2010; Pantaleo et al. 2013; Walekhwa et al. 2014; FEA 2014; GIZ 2016).

Therefore, based on the information obtained from the various sources, the total sanitation system costs (**TSSC**) were computed with reference to the respective sanitation systems. Furthermore, estimation of the operating costs, which comprised of net operating costs, maintenance and financing as well as insurance costs was carried out. Besides, the computation of the benefits for the respective sanitation systems additionally factored in the environmental and health benefits already discussed.

All estimations were converted to Uganda shillings (UGX) from Euros (€). The total discounted costs and revenues were then applied for computation of the **NPV**, **IRR**, **PBP** and a sensitivity analysis was carried out at a later stage. Figure 9-2 gives an overview of procedure adapted for assessment of the economic feasibility of the sanitation system alternatives proposed for **UCU**.

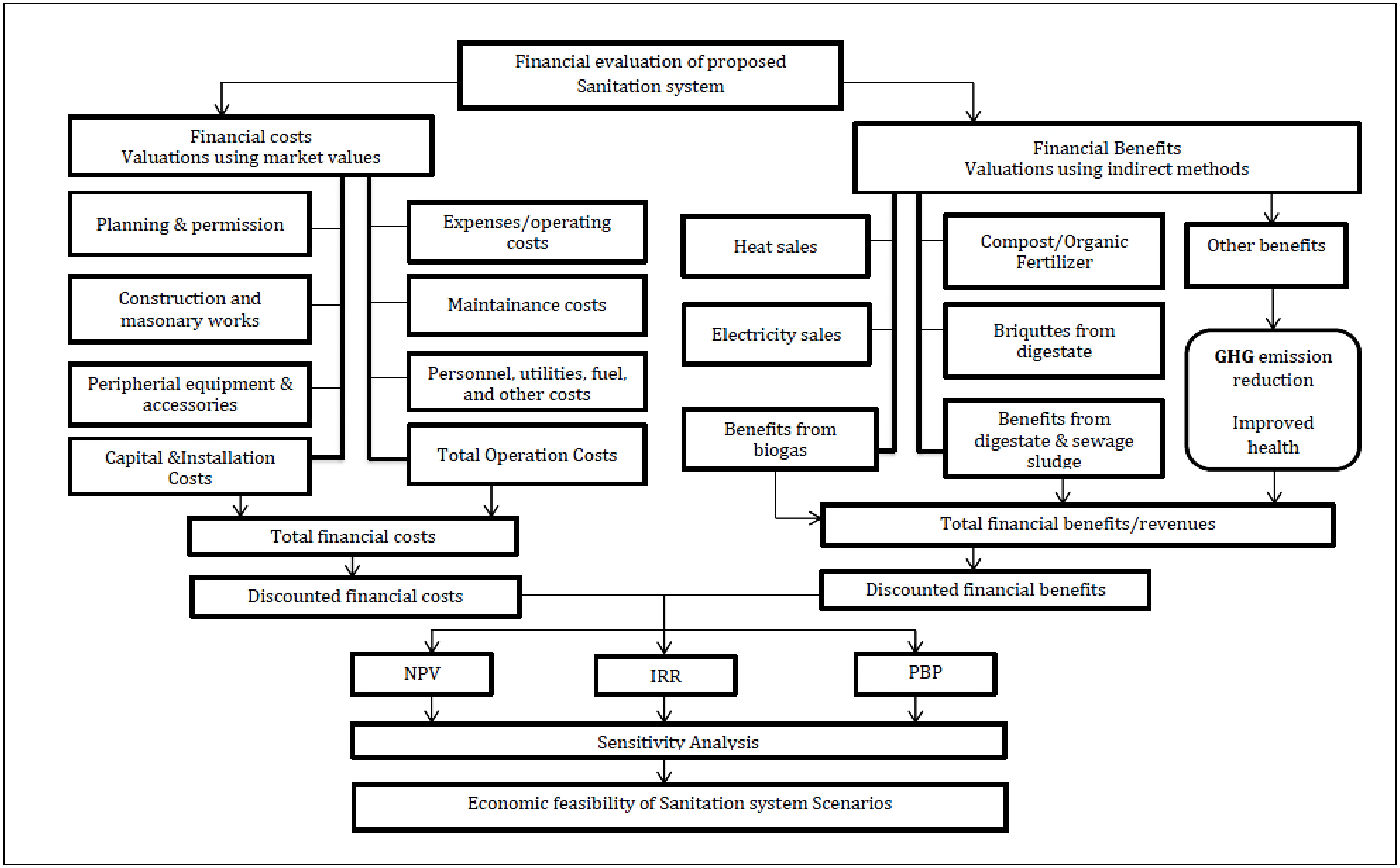

Figure 9-2: Framework for assessment of economic feasibility of sanitation system alternatives proposed for UCU
Source: Author, modified from (Walekhwa et al. 2014)

9.4.1 Investment Costs

As initially noted, the investment costs for the various components of the sanitation systems were obtained from supplier information and reference to literature. Particularly with reference to anaerobic digester units considered for the respective sanitation systems, investments cost estimations were based on the potential amount of biogas that would be generated from the respective systems. Moreover, given that **UCU** is a privately run University, development of any project within the University is entirely the responsibility of the University. Such projects are often funded by the University`s own resources in addition to loans obtained from financial institutions. Furthermore, the interest of the University to improve sanitation while recovering energy in the form of biogas is an additional driving factor for the possible implementation of any of the proposed sanitation systems. Therefore, with reference to this background, equity capital of 30% was assumed and used in computations carried out.

With reference to the loans anticipated from the financial institutions, an interest rate of 10% was considered. This value was based on consultation with key informants from **GIZ**[19] -Uganda and Uganda Energy Credit Capitalisation Company **(UECCC),** which is Government institution set up primarily to facilitate investments in Uganda's Renewable Energy Sector. The **UECCC** particularly focuses on enabling private sector participation in renewable energy implementation. While **GIZ** is one of the key **NGO`s** in corporation with the Ministry of Energy and Mineral Development (**MEMD)** with regards to bioenergy and solar related projects among others.

9.4.2 Total Sanitation System Costs (TSSC)

Estimation of capital costs for the respective sanitation system alternatives reflected the variation in system components. Moreover, often the case, investment cost figures for biogas plants/units vary extremely on the basis of the technology and various equipment included. Such variations may be evident with regards to pre-treatment, storage and handling modules of different input feed stocks. Furthermore, investment cost figures often mean different things to equipment suppliers depending on the limits and boundaries of the equipment and services offered. Taking these variations into consideration, the anaerobic digestion unit considered various components/additions such as pretreatment units for different substrates and digestate storage units among others.

Reference to supplier information and relevant literature informed specific component cost estimation for the various sanitation system alternatives(Karellas et al. 2010; Hahn 2011; FEA 2014; Walekhwa et al. 2014; GIZ 2016). Besides, reference to regional (Africa) and national literature for similar component or technology installations was considered to ensure that estimations made were reflective of the **UCU** scenario. All capital cost items were incorporated in the "so-called" total sanitation system cost (TSSC or ''turn-key'' cost) and these included;

[19] GIZ; Deutsche Gesellschaft für Internationale Zusammenarbeit; collaborate with the Ministry of Energy & Mineral Development, Uganda in providing support on biogas related projects.

- Costs of the various components of the sanitation systems and equipment
- Costs for erection, instrumentation, electrical & civil works.
- Planning design and permitting costs

Moreover, necessary contingency costs were also considered. Thus, the capital or investment costs for various components of the sanitation systems were computed with reference to information obtained from the various source and were represented as the **TSSC** summarised in Table 9-2

Table 9-2: Guidance for components capital estimation

Cost component	Cost as % of Initial plant cost
Biogas plant-Item costs	
Digester	33-37
Pump & stirrer	7-9
CHP	21-23
Power connection	1-3
Feeding system	6-8
Measurement &Control	2-5
Heating	4-6
Feedstock Storage	8-10
Digester Storage	8-10
Total plant costs	
Other component costs	Supplier information
Composting unit	
Solar dryer	
Incinerator	
Briquetting machine	
Direct costs	
Planning, design and permission	7-8%
Contingency	5-7%
Total Sanitation system-cost (TSSC)	

Sources: Supplier information,
(Hahn 2011; Deublein, and Steinhauser 2011; Walekhwa et al. 2014; GIZ 2016)

Noteworthy is that this capital cost estimation guide was used specifically for the sanitation systems considered since reference was made to the various sources of information already mentioned. Thus, in case of system scalability, further considerations would have to be incorporated, especially with regards to supplier information for other components.

9.4.3 Operational Costs and Revenues

The operation costs for the sanitation system alternatives were categorised into six key items as described in the following Section.

9.4.3.1 Personnel and General costs

The overall labor expenses were computed with reference to the daily requirements, which were later used to compute annual labor expenses. For most of the tasks proposed for the specific sanitation systems, a duration of 315 days a year was considered with reference to the number of days in each academic year at **UCU.** Also, the general costs calculated as overheads for the personnel were assumed to be 5% of personnel costs. This assumption was based on the fact that additional sanitation system components such as the biogas digester, composting unit, solar drying unit, incinerator and briquetting units, would complement the existing sanitation system at **UCU**. Thus, additional overhead costs which are often assumed as 10% of the personnel cost were halved (Karellas et al. 2010).

9.4.3.2 Maintenance Costs

Annual maintenance and repair costs that would be incurred in obtaining spare parts and external assistance for the various system components were computed with reference to the percentage of component costs. Based on the various sources referred to i.e. supplier information and relevant literature, maintenance costs were in the range of 3-5% of the capital and installation costs (Karellas et al. 2010; Hahn 2011; Walekhwa et al. 2014; GIZ 2016).

9.4.3.3 Annual Expenses

In this category, allocation of costs for the various components of the sanitation system alternatives was carried out for the respective useful life of each component (Hahn 2011). These costs were computed based on an annuity factor (**A_f**), which factored in the duration of depreciation and the interest rate as shown in Equation 9-4.

$$A_f = \frac{1-(1+r)^{-n}}{r} \qquad \text{Equation 9-4}$$

Where **A_f** is the Annuity factor, **r** is the interest rate and **n** the depreciation period of component/asset.

Once the annuity factor was computed, the annual expenses for specific system components were then computed based on Equation9-5.

$$E=C_c/A_f$$ ……………………………………………………….Equation 9-5

Where **E**; expenses and **Cc** the component capital cost.

9.4.3.4 Utilities

In terms of utility requirements, electricity to run all the various system components, especially auxiliary equipment such as pumps, blowers, fans, feeding systems, etc. was considered. Other utilities such as heat required to maintain the digester at mesophilic conditions were catered for within the energy requirement for operating the sanitation system. Particularly with reference to biogas plants generating electricity through **CHP** units, electricity requirement within the plant is estimated to range between 5-10% of own electricity generated (Al Seadi et al. 2008; Hahn 2011). Thus, with reference to this information, the overall electricity required within the sanitation systems was assumed to be 7% of the own electricity generated from the **CHP** unit. This estimation was also used to inform the computation of electricity required for the sanitation systems when biogas was used directly for cooking. Hence, the cost of electricity consumed by each sanitation system alternative was deducted from the potential revenues obtained due to the sale of generated electricity by respective sanitation systems.

9.4.3.5 Transportation Costs

Usually when ''classical'' organic wastes are considered, disposal in designated plants such as biogas plants provides the plant operator with a certain benefit in the form of negative ''gate fees'' (Karellas et al. 2010; Hahn 2011). A similar consideration was taken into account thus, the further treatment of sewage and faecal sludge in **COMPAD**, **COMPAD LF, INCAD**, **INTEG 1** and **INTEG 2** alternatives constituted revenue for the respective systems in the form of gate fees. The negative gate fees were estimated as the costs that **UCU** would incur in case of further treatment or management of sewage sludge at designated plants. The designated plants considered were Lubigi and Bugolobi faecal sludge, which additionally had **WWT** plants operated by the National Water and Sewerage Corporation (NWSC). While the fees that private customers would pay for treatment and management of faecal sludge at **UCU** was estimated as an additional negative gate fee for **INTEG 2** alternative. On the other hand, positive gate fees were assumed for the **Status Quo** alternative, where transportation of the partially stabilised sewage sludge for further management/disposal at designated plants would be incurred by **UCU.** Although no costs would be incurred in obtaining substrate generated at **UCU,** the transportation of cow dung from the University farm located at **Ntawo** about 3.5km from **UCU** campus was considered a positive gate fee.

9.4.3.6 Other Costs

This category of costs included sanitation system insurance costs computed as 3% of the investment cost. According to literature on insurance premium ranges for various related projects in Uganda, the insurance estimations ranged between 0.85-3% (IRA 2016).

Thus, 3% of investment costs were considered since no specific estimates were given for sanitation related projects. Moreover, costs incurred for purchasing consumables such as oil required for the **CHP** unit, incinerator and briquetting machine were also considered. The costs for other inputs such as lime and active carbon for removal of odors and noxious gases from the biogas digester were catered for under overhead costs.

9.4.3.7 Revenue

The potential annual revenues accrued from the operation of each sanitation system alternative were computed based on own generated electricity and heat from the **CHP** unit. Utilisation of biogas for cooking or electricity and heat generated from **CHP** at **UCU** was taken into account**.** Thus**,** computation of electricity sales were based on the estimated cost of 1kWh of electricity used while the heat sales were computed taking into consideration the conversion of heat generated for heating water later used for cooking purposes. In the case when biogas was considered directly for cooking, computation of the amount of firewood replaced was carried out.

Furthermore, revenues accrued from the proposed sale of compost, stabilised digestate as organic fertilizer and briquettes produced from digestate were also computed. The negative gate fees that would otherwise be incurred from transportation of sewage sludge and faecal sludge for further management/disposal at designated plants were computed as revenue for all alternatives except the **Status Quo** (refer to explanation in Section 9.4.3.5). As noted, the assumption that sewage sludge from **UCU** lagoons would be transported for further treatment at either Lubigi or Bugolobi faecal sludge plants at a cost was considered. Equations 9-6 and 9-7 were used to compute electricity and heat sales respectively for the sanitation system alternatives.

$$Es = Ea * Ue \qquad \text{Equation 9-6}$$

$$Hs = Ha * Ecf \qquad \text{Equation 9-7}$$

Where E_s; represents electricity sales E_a; amount of electricity generated annually and **Ue** the unit cost of electricity in kWh. While **Hs** represents heat sales, **Ha** the annual amount of heat utilised for cooking. **Ecf** was the unit cost of heat from firewood which additionally incorporated a conversion factor of heat from biogas in relation to heat from firewood.

Furthermore, the environmental benefits were based on the potential returns from reduction in greenhouse gas (**GHG**) emissions from the respective sanitation system alternatives.

Specifically, the biogas generated from the respective system alternatives considered either for cooking or cogeneration purposes was estimated as the avoided **GHG** emissions. Given that **GHG** emissions are responsible for global warming, the avoided emissions were considered to represent reduction in global warming potential, which is expressed as a factor of carbondioxide (CO_2). Given that the composition of biogas considered was 60% for methane and 40% for carbon dioxide, the methane portion in biogas was converted to carbon dioxide equivalent. A conversion factor of 28 was used since methane is considered to be 28 times the global warming potential of carbon dioxide for 100 year time horizon(GGP 2014; Trottier 2014). The total carbon dioxide equivalent of the biogas generated was then converted to one ton of carbon dioxide equivalent (CO_2-eq), which is assigned a value ranging between 5-10US$ according to literature (WSP 2012; Mittal 2011). For computation of the revenue from **GHG** reduction, a value of 5US$ per ton of CO_2 equivalent was used. Thus, Equations 9-8 and 9-9 were used to compute the returns from GHG reduction;

$$CO_{2CH4} = B_g * 0.6 * 28 \quad \text{.................................Equation 9-8}$$

Where $\mathbf{CO_{2CH4}}$ is the carbon dioxide equivalent (kg) from the methane portion in biogas.

$$GHG_r = (CO_{2CH4} + CO_2) * 5US\$/1000 \quad \text{.................................Equation 9-9}$$

Where $\mathbf{CO_2}$ is the remaining amount of CO_2 in the biogas and $\mathbf{GHG_r}$ is the revenue from reduction of **GHG.**

Finally, the health benefits associated with installing any of the sanitation systems were computed with reference to three key aspects i.e savings related to seeking less health care, savings related to productive time losses from disease and savings related to reductions in premature mortality as already discussed in Section 9.2. National literature was referred to thus, quantified financial resources lost annually as a result of premature death, productivity losses while sick or accessing health care and money spent on health care associated with poor sanitation was used (WSP 2012).

Moreover, reference was made to suggestions by Hutton (2015), who points out that improved sanitation with formal excreta management contributes to reduction in diarrheal and consequent diseases by 69% compared to unimproved facility (Hutton 2015, 2012). Therefore, taking into consideration the population size of **UCU** as 4,000 people for a given duration (May-August 2016), revenues accrued from improved health by the sanitation system alternatives was computed. In computing these values, inflation rates were incorporated to reflect the current estimates since most of the data used was from the duration 2012-2015.

9.5 Key Assumptions Considered

The computation of all costs and revenues was based on the following key assumptions;

- Equity capital was assumed as 30% of the investment costs for the sanitation systems.
- Fugitive emissions from the biogas plant accounted for 7% the biogas amount generated (refer to Chapter 8).
- An interest rate of 10% was used and this was based on key informant interviews from **GIZ** -Uganda and Uganda Energy Credit Capitalisation Company **(UECCC).**
- While the loan payback period was assumed to 10 years

Computation of the total operation costs (**TOC**) and revenues was carried out for all sanitation system alternatives. For all sanitation system alternatives which consisted of an anaerobic digestion unit, two scenarios were considered i.e.; utilisation of biogas directly for cooking (**BfC**) and utilisation of biogas for cogeneration (**CoGen**) as was the case during the environmental feasibility assessment (refer to chapter 8). Thus, the **TOC** and revenues for the respective sanitation system alternatives are summarised in Table 9-3 to Table 9-6, while Table 9-7 gives an overall assessment of the sanitation system alternatives.

Table 9-3: Summary of TOC for Sanitation System Alternatives-Biogas used for Cooking (BfC)

Item No	Costs(UGX)	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2	Status Quo
A	***Fixed Operational Costs(FOC)***						
1	Personnel/labor	33,052,845	29,531,282	30,164,193	30,164,193	31,275,213	
	Overhead	1,186,014	1,009,936	1,041,581	1,041,581	1,097,132	
	Total FOC	**34,238,859**	**30,541,218**	**31,205,774**	**31,205,774**	**31,372,345**	
B	***Variable Operation Costs(VOC)***						
1	Maintenance	4,168,744	3,410,250	5,496,042	5,370,343	7,234,171	3,145,307
2	Operating/Expenses	36,102,397	27,418,949	43,322,968	45,970,476	57,970,215	
3	Fuel/transportation costs	3,499,713	3,499,713	3,499,713	3,499,713	3,499,713	
C	Others(Variable costs)						
1	Insurance	9,473,958	7,840,758	10,420,280	10,276,706	15,960,065	
2	Consumables	9,892	9,892	19,784	9,892	19,784	
	Total VOC	53,254,704	42,179,562	62,758,787	65,127,130	84,683,948	
	Total Operation Costs	**87,493,563**	**72,720,780**	**93,964,561**	**96,332,904**	**116,056,293**	**3,145,307**

Conversion rate used 1Euro=3703.4UGX

Table 9-4: Summary of TOC for Sanitation System Alternatives- Biogas is used for Cogeneration (CoGen)

Item No	Costs(UGX)	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2	Status Quo
A	***Fixed Operational Costs(FOC)***						
1	Personnel/labor	33,052,845	29,531,282	30,164,193	30,164,193	31,275,213	
	Overhead	1,186,014	1,009,936	1,041,581	1,041,581	1,097,132	
	Total FOC	**34,238,859**	**30,541,218**	**31,205,774**	**31,205,774**	**31,372,345**	
B	***Variable Operation Costs(VOC)***						
1	Maintenance	12,166,851	11,389,158	13,494,114	16,008,398	22,204,885	3,145,307
2	Operating/Expenses	47,608,047	38,473,086	54,828,618	61,273,806	79,506,264	
3	Fuel/transportation costs	3,499,713	3,499,713	3,499,713	3,499,713	3,499,713	
C	Others(Variable costs)						
1	Insurance	9,473,958	7,840,758	10,420,280	10,276,706	15,960,065	
2	Consumables	9,892	9,892	19,784	9,892	19,784	
	Total VOC	**72,758,461**	**61,212,607**	**82,262,509**	**91,068,515**	**121,190,711**	
	Total Operation Costs (A+B+C)	**106,997,320**	**91,753,825**	**113,468,283**	**122,274,289**	**152,563,056**	**3,145,307**

Source: Author

Table 9-5: Summary of Revenues for Sanitation System Alternatives- Biogas is used for Cogeneration (CoGen)

Item No	Revenue(UGX) From sales	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2	Status Quo
1	Electricity sale	79,153,820	79,153,820	79,153,820	105,280,196	148,158,560	
2	Heat sale	35,691,976	35,691,976	35,691,976	47,472,860	66,807,537	
3	Compost sale	39,365,525	36,486,908				
4	Digestate as fertilizer	6,526,539	6,526,539	6,526,539			
5	Processed digestate-fertilizer				33,045,083	28,696,165	
6	Briquettes from digestate					57,404,255	
7	Energy recovery from incinerator			29,095,012			
8	GHG emission reduction	26,021,940	26,021,940	26,021,940	34,612,162	48,704,895	
9	Improved Health	14,848,264	14,848,264	14,848,264	14,848,264	14,848,264	7,424,132
10	**Gate fees**						
	Sewage sludge	4,707,021	4,707,021	4,707,021	4,707,021	4,707,021	
	Faecal Sludge					103,695	
	Total revenue	206,315,085	203,436,468	196,044,572	239,965,586	369,430,392	7,424,132

Source: Author

Table 9-6: Summary of Revenues for Sanitation System Alternatives- Biogas is Used for Cooking (BfC)

Item No	Revenue(UGX) From sales	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2	Status Quo
1	Use of biogas to replace wood	58,342,653	58,342,653	58,342,653	77,600,676	109,204,485	
3	Compost sale	39,365,525	36,486,908				
4	Digestate as fertilizer	6,526,539	6,526,539	6,526,539			
5	Processed digestate-fertilizer				33,045,083	28,696,165	
6	Briquettes from digestate					57,404,255	
7	Energy recovery from incinerator			29,095,012			
8	GHG emission reduction	26,021,940	26,021,940	26,021,940	34,612,162	48,704,895	
	Improved Health	14,848,264	14,848,264	14,848,264	14,848,264	14,848,264	7,424,132
8	**Gate fees**						
	Sewage sludge	4,707,021	4,707,021	4,707,021	4,707,021	4,707,021	
	Faecal Sludge					103,695	
	Total revenue	**149,811,942**	**146,933,325**	**139,541,429**	**164,813,206**	**263,668,780**	**7,424,132**

Source: Author

Table 9-7: Summary of Economic Evaluation of Sanitation System Alternatives for both Scenarios

Item	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2	Status Quo
Investment cost(UGX)-CoGen	331,588,525	274,426,546	364,709,809	359,684,710	558,602,272	5,443,998
Investment cost-BfC	271,045,568	217,919,786	304,166,852	279,158,282	445,279,159	
Project Financing						
Equity Capital	30%	30%	30%	30%	30%	
Loan	70%	70%	70%	70%	70%	
Loan Assumptions						
Interest rate	10%	10%	10%	10%	10%	
Payback period	10 years	10 years	10 years	10 years	10 years	
Grace period	1 year	1 year	1 year	1 year	1 year	
Revenues -CoGen(Table 9-5)	206,315,085	203,436,468	196,044,572	239,965,586	369,430,392	7,424,132
Revenues-BfC (Table 9-6)	149,811,942	146,933,325	139,541,429	164,813,206	263,668,780	
Total operating costs(TOC)						
After taxation (18%)						
TOC-CoGen	133,287,445	115,300,097	140,923,224	153,634,864	194,364,142	3,145,307
TOC-BfC	108,231,462	90,935,656	115,867,240	120,308,628	147,464,847	
Annual income						
(Revenues-TOC after taxation)						
Total annual income-CoGen	73,027,641	88,135,378	54,121,348	86,330,722	175,066,250	4,278,825
Total annual income-BfC	41,580,481	55,996,677	22,674,189	44,504,578	116,203,934	
Financial Evaluation						
NPV 20years- CoGen	290,136,945	475,427,399	96,055,737	375,297,396	931,835,406	30,983,329
NPV 20years-BfC	82,952,506	266,378,354	-111,128,703	98,629,322	549,714,885	
Payback period(PBP)-CoGen	4.5years	3.1 years	6.7 years	4.2 years	3.2 years	1.3 years
PBP- BfC	6.5years	3.9years	13.4years	6.3years	3.8years	
IRR 20 years –CoGen	22%	32%	14%	24%	31%	79%
IRR 20 years- BfC	14%	25%	-	15%	26%	

Source: Author **Note: All monetary values are represented in Uganda shillings (UGX)**

In the economic evaluation of the sanitation system alternatives shown in Table 9-7, value added taxes (VAT) were excluded when computing the capital costs for the various sanitation system components. The tax exemption was based on the assumption that **UCU** as an institute of higher learning would benefit from the incentives proposed in the ***National Renewable Energy Policy*** of the Government of Uganda. The Policy whose goal is to increase the use of modern renewable energy to 61% of the total energy consumption by 2017, also proposes to promote the conversion of waste to energy and this is catered for in the sanitation systems evaluated. Among the policy action points to boost renewable energy project implementation are the exemption of duty and tax free import on plant and machinery equipment, in addition to provision of incentives for renewable energy related projects (MEMD 2012). Therefore, with reference to this background, it was assumed that **UCU** in implementing any of the chosen waste to energy sanitation systems would be exempted from taxation during the purchase of the various system components. However, taxation was incorporated in the computation of the total operating costs, which basically included the fixed and variable operation costs. A value added tax of 18% used in Uganda was incorporated in the computation of the total operation costs for each of the sanitation systems (URA 2014).

9.6 Discussion of Results

Based on the assumptions initially considered, the financial evaluation of the sanitation system alternatives summarised in Table 9-7 indicated variable trends of performance with respect to the parameters i.e. **NPV**, **PBP** and **IRR**. With reference to the **CoGen** scenario, all sanitation system alternatives registered positive **NPVs.** Specifically, the trend of performance showed that the **INTEG 2** alternative performed best followed by the **COMPAD LF**, **INTEG 1**, **COMPAD, INCAD** and finally **Status Quo.** The higher the annual income accrued by the respective sanitation system alternatives, the higher the **NPV**. Thus, the good performance of the **INTEG 2** alternative was attributed to the higher annual income additionally contributed to by energy recovery in form of briquettes and the environmental benefits due to reduced **GHG** emissions.

Still considering the **CoGen** scenario, all sanitation system alternatives registered **PBPs** less than the 10 year loan **PBP** considered. The trend of performance for the sanitation system alternatives with reference to the **PBP** showed that the **Status Quo** alternative performed best registering a duration of only 1.3 years followed by the **COMPAD LF** alternative with a **PBP** of 3.1years, **INTEG 2** at 3.2years, **INTEG 1** at 4.2 years, **COMPAD** at 4.5years and finally the **INCAD** alternative with a **PBP** of 6.7 years. Although the **Status Quo** alternative performed very well in comparison to the other alternatives, it should be noted that since no major installations were considered for the system alternative, the overall costs were minimal. Moreover, the main sources of revenue for the system alternative were from the health benefits since no significant returns were registered from resource recovery. The much better performance of the **COMPAD LF** alternative in comparison to **INTEG 2**, **INTEG 1**, **COMPAD**, and **INCAD** alternatives was attributed to the slightly lower investment costs of the system alternative.

Given that the **COMPAD LF** alternative considered utilisation of existing composting plant facilities at Mukono Municipal Landfill, new composting plant installation costs were avoided, contributing to the system`s lower overall investment costs. This implied that a lower **PBP** was computed for the **COMPAD LF** in comparison to the mentioned system alternatives. Noteworthy was that the difference in **PBP** between the **COMPAD LF** and **INTEG 2** alternatives was only 1 month. While the difference in **PBP** between **INTEG 1** and **COMPAD** was only 3 months. These slight differences in **PBP** were particularly attributed to the high annual income accrued by **INTEG 2** and **INTEG 1** respectively. Thus, despite the avoided composting unit costs considered for the **COMPAD LF** alternative, the increased income anticipated from the **INTEG 2** alternative contributed to the slight difference in **PBP** between the two system alternatives. Meanwhile, with reference to the **IRR**, the trend of performance was similar to that of the **PBP** with the **Status Quo** alternative performing well with an **IRR** of 79% followed by the **COMPAD LF** registering a value of **32%, INTEG 2** with a value of 31%, **INTEG 1** registering a value of 24%**, COMPAD** a value of 22% and finally the **INCAD** alternative with an **IRR** value of 14%. Moreover, a similar explanation holds as was the case for **PBP**. An overall trend of performance based on the ranking of all the three parameters for each of the sanitation system alternatives when **CoGen** scenario was considered showed a trend of **COMPAD LF>INTEG 2>Status Quo>INTEG 1>COMPAD>INCAD**.

With reference to the utilisation of biogas for cooking (**BfC**) scenario, all sanitation system alternatives except the **INCAD** alternative registered positive **NPVs.** This time round, the trend of performance showed that the **INTEG 2** alternative performed best followed by the **COMPAD LF**, **INTEG 1**, **COMPAD**, **Status Quo** and finally the **INCAD** alternative. The negative **NPV** for the **INCAD** alternative was due to the much lower income accrued by the alternative in comparison to the overall investment of the system. Given that the sewage sludge was considered for incinerated in the **INCAD** alternative, the only resources that would be accrued in the form of organic fertilizer were from the anaerobic digestion unit. As such, the overall annual income from the system alternative was lower in comparison to other alternatives except the **Status Quo** alternative. Despite having a much lower annual income, the better performance of the **Status Quo** alternative in comparison to the **INCAD** alternative was attributed to the minimal installations considered for the **Status Quo** alternative. For this alternative, the main installation considered was the modification of existing lagoons at the **WWTP** at **UCU** to incorporate a roofing structure. These modifications would allow for improved sewage sludge drying in the lagoons, especially during rainy seasons.

With reference to the **PBP**, the trend of performance showed that the **Status Quo** alternative performed best registering a duration of only 1.3 years followed by the **INTEG 2** alternative at 3.8years, **COMPAD LF** at 3.9 years, **INTEG 1** at 6.3 years, **COMPAD** at 6.5 years and finally the **INCAD** alternative registering a **PBP** of 13.4years. As already mentioned, the good performance of the **Status Quo** alternative was attributed to the minimal installation costs incurred while the much lower annual income of the **INCAD** alternative in comparison to the system investment costs also contributed to a **PBP** greater than the loan **PBP** of 10 years.

As was the case in the **CoGen** scenario, the higher the annual income of the sanitation system, the better the performance of the sanitation system with the exception of the **Status Quo** alternative, whose much lower installation costs additionally contributed to its good performance in terms of **PBP** and **IRR**. Meanwhile, with reference to the **IRR**, a similar trend of performance to the **PBP** was traced for the system alternatives i.e. **Status Quo>INTEG 2>COMPAD LF>INTEG 1>COMPAD >INCAD.** An overall trend of performance when all three parameters were considered showed that **INTEG 2 >Status Quo>COMPAD LF>INTEG 1>COMPAD>INCAD**. In this scenario, the **INTEG 2** alternative performed better than the **COMPAD LF** alternative.

Generally, for system alternatives which consisted of the anaerobic digestion unit, the results showed better performance when the **CoGen** scenario was considered in comparison to when the **BfC** scenario was considered for all parameters. The **NPVs** and **IRR** values were much higher for all system alternatives when the **CoGen** scenario was considered in comparison to **BfC**. While the **PBPs** were much lower and the **IRR** values were much higher for all system alternatives when **CoGen** was considered in comparison to **BfC** scenario. Moreover, it would suffice to say that all sanitation system alternatives could be considered economically feasible when the **CoGen** scenario was considered. While the **INCAD** alternative was considered not feasible in case the **BfC** scenario was taken into account.

Having identified certain hot spots from the assessment of the sanitation system alternatives discussed, a sensitivity analysis was carried out fully appreciate the influence of adjustments to the performance of the system alternatives. In the sensitivity analysis, variation of the interest rate, percentage of equity capital and biogas losses anticipated was carried out.

9.7 Sensitivity Analysis

The sensitivity analysis included adjustments of key assumptions considered in the computation of the economic feasibility of sanitation system alternatives and this allowed for incorporation of any uncertainty. Given that better performance was registered for all sanitation system alternatives when **CoGen** scenario was considered in comparison to when the **BfC** scenario was considered, the sensitivity analysis focused on the **CoGen** scenario. Thus, the following adjustments to the assumptions were considered;

- Reduction of fugitive emissions from the biogas plant to 5% and later to 3% was considered since the initial computation of **NPV**, **IRR** and **PBP** factored in the worst case scenario of fugitive emission of up to 7% of the biogas produced. The adjustment in fugitive emissions considered was based on experiences in measurement of fugitive emissions at biogas plants mostly in European countries, which registered fugitive emissions in the range 3-10% (Jonerholm and Lundborg 2012; Jørgensen and Kvist 2015)

- Adjustment of the interest rate from 10 % to 12%, which is also used conventionally to annualise capital payments in certain developing countries such as Uganda with reference to a study by (Walekhwa et al. 2014) was carried. Furthermore, a 5% discount rate was considered based on the assumption that a credible relationship between **UCU** and other financial institutions could influence reduction in the interest rate on loans acquired.

- Lastly, variation of equity capital for investment from 30 %(**base case)** to 20 %(**worst case**) and finally 40 %(**best case**) was considered. The projection that equity capital would be contributed for the implementation of any selected sanitation system was based on the fact that being a private University, **UCU** funds most of her projects. Moreover, the fact the **UCU** is interested in shifting from the dependence on firewood for cooking to cleaner energy sources such as biogas while managing sewage sludge from the **WWTP** was an additional motivating factor (UCU 2012). Results from the sensitivity analysis are summarised in Table 9-8.

Table 9-8: Summary of Sensitivity Analysis for Sanitation System Alternatives

Sensitivity analysis conditions	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
5% fugitive emission					
NPV20years(UGX)	308,152,763.25	493,935,431	114,071,555	399,259,712	965,557,058
Payback period(PBP)	4.4 years	3	6.5years	4 years	3.1 years
IRR 20 years	22%	33%	15%	25%	32%
3% **fugitive emissions**					
NPV20years(UGX)	326,168,581	511,951,249	132,087,372	423,222,027	999,278,711
Payback period(PBP)	4.3years	3 years	6.2 years	4 years	3.1 years
IRR own capital 20 years	23%	34%	15%	25%	33%
Interest rate of 12%					
NPV20years(UGX)	166,861,677	348,125,815	-13,475,440	225,134,122	673,375,481
Payback period(PBP)	5 years	3.3years	7.8 years	4.6 years	3.4 years
IRR 20 years	20%	30%	12%	21%	29%
Interest rate of 5%					
NPV20years(UGX)	758,345,656	961,221,920	512,779,992	945,854,700	1,913,137,134
Payback period(PBP)	3.8years	2.8years	5.2	3.4	2.8
IRR 20 years	26%	36%	19%	30%	35%
Equity capital 20%					
NPV20years(UGX)	170,057,893	366,350,433	-30,113,036	230,541,135	718,483,972
Payback period(PBP)	6 years	4 years	9.2years	5.5years	4years
IRR own capital 20 years	16%	25%	9%	18%	25%
Equity capital 40%					
NPV20years(UGX)	408,744,616	585,488,794	222,224,510	520,053,657	1,145,186,839
Payback period(PBP)	3.5 years	2.4 years	5 years	3.2 years	2.5 years
IRR own capital 20 years	28%	41%	20%	31%	40%
No Equity capital					
NPV20 years(UGX)	-70,100,213	147,212,073	-282,450,583	-58,971,387	291,781,105
Payback period(PBP)	10 years	6.2 years	18.6 years	9.6 years	6.2 years
IRR 20 years	8.3%	15%	1%	8.5%	15.2%
Benefit Cost Ratio-Base Case	**1.55**	**1.76**	**1.38**	**1.56**	**1.9**

Source: Author

9.7.1 Scenario 1

Within this scenario, the amount of fugitive emissions from the anaerobic digester were adjusted and a reduction of fugitive emissions from 7% to 5% and finally 3% was considered while maintaining an interest rate of 10% and equity capital at 30%. With reference to the **NPV**, all sanitation system alternatives which consisted of the anaerobic digestion unit registered positive **NPVs**. Moreover, the trend of performance with reference to the **NPV** showed that the **INTEG 2** alternative performed best followed by **COMPAD LF, INTEG 1**, **COMPAD** and finally the **INCAD** alternative**.** Reduction of the fugitive emissions to 3% showed that the **NPVs** increased by at least 7% in comparison to the base case scenario for all sanitation system alternatives considered**.** Increase in **NPVs** would be expected since the decrease of fugitive emissions implied that additional biogas would be available for cogeneration of electricity and heat. The increased sales from electricity and heat would then contribute to an increase in the income, which would in turn positively influence the **NPVs** of the respective sanitation system alternatives.

Meanwhile, with reference to the **PBP,** all sanitation system alternatives registered a **PBP** less than the 10 year **PBP** considered**.** The trend of performance showed that the **COMPAD LF** alternative performed best registering a 3 year **PBP** followed by the **INTEG 2** at only **3.1**years, **INTEG 1** at 4 years, **COMPAD** at 4.3 years and finally the **INCAD** alternative at 6.2 years. The better performance of the **COMPAD LF** alternative was additionally attributed to the avoided composting plant installation costs since an already existing composting plant at Mukono landfill was considered for use. A similar trend of performance was noted for all sanitation system alternatives with reference to the **IRR.** The decrease of the fugitive emissions from 5% to 3% did not affect the **PBP** of the **INTEG 2, INTEG 1** and the **COMPAD LF** alternatives while slight variations in the range of 1-3 months were noted for the **COMPAD** and **INCAD** alternatives respectively. Moreover, the **INTEG 1** and **INCAD** alternatives did not register any variation in **IRR** values when fugitive emissions were reduced from 5% to 3% while only a 1% increment in the **IRR** value was noted for **INTEG 2**, **COMPAD** and **COMPAD LF** alternatives ,

9.7.2 Scenario 2

Adjustment of the interest rate to 12% while maintaining fugitive emissions of 7% and equity capital contribution of 30% resulted in positive **NPVs** for all other alternatives except the **INCAD** alternative which registered a negative **NPV**. Moreover, an overall reduction in **NPV** of at least 27% was registered for the **COMPAD**, **COMPAD LF, INTEG 1** and **INTEG 2** alternatives in comparison to the **NPVs** computed when the base case conditions were considered. The trend of performance showed that the **INTEG 2** alternative performed best followed by the **COMPAD LF**, **INTEG 1**and finally the **COMPAD** alternative. Meanwhile, with reference to the **PBP** and **IRR**, the trend of performance was similar to that discussed in **Scenario 1** with the **COMPAD LF** alternative performing best followed by **INTEG 2, INTEG 1, COMPAD** and finally the **INCAD** alternative. In comparison to the based case scenario, slightly higher **PBPs** and lower **IRR** values were registered for all sanitation system alternatives.

Adjusting the interest rate to 5% no doubt resulted in much higher **NPVs**, much lower **PBPs** and slightly higher **IRR** values for all sanitation system alternatives. The **NPVs** for all the sanitation system alternatives considered increased by at least 100% when compared to the **NPVs** obtained during the base case scenario. With reference to the **PBP,** the **COMPAD LF** and **INTEG 2** alternatives registered minimal reduction of only 3 months. While the **COMPAD** and **INTEG 1** alternatives registered a reduction in **PBP** of at least 7months and the **INCAD** alternative registered a reduction in **PBP** of more than a year. Reduction in the **IRR** values of at least 5% was noted for all the sanitation system alternatives in this scenario as compared to the base case scenario.

9.7.3 Scenario 3

Not surprisingly, reduction of the equity capital to 20% resulted in reduction of **NPVs** by at least 22% for the **COMAPD, COMPAD LF, INCAD, INTEG 1**and **INTEG 2** alternatives in comparison to the base case scenario. In particular, the **INCAD** alternative registered a negative **NPV** value while the **PBPs** for all the system alternatives increased and the **IRR** values decreased. Noteworthy was that the **PBP** of the **COMPAD LF** and **INTEG 2** alternatives increased minimally by at least 7 months while for the **INCAD**, **COMPAD** and **INTEG 1** alternatives, the **PBP** increased by at least 1 year. Adjustment of equity capital to 40% resulted in increased **NPVs**, much lower **PBPs** and much higher **IRR** values for the sanitation system alternatives in comparison to the base case scenario. Moreover, the **INCAD** alternative also registered a positive **NPV** of at least 500million UGX, yet a negative **NPV** had been registered when the equity capital of 20% was applied. The trend of performance was maintained with the **INTEG 2** alternative performing best followed by the **COMPAD LF**, **INTEG 1**, **COMPAD** and finally **INCAD** alternative. A final adjustment to check the influence of absence of equity capital on sanitation system performance showed that only the **COMPAD LF** and **INTEG 2** alternatives were feasible with regards to **NPV.** The remaining system alternatives i.e. the **COMPAD, INCAD** and **INTEG 1** registered negative **NPVs.** Besides, the **INCAD** alternative was considered not feasible even when the **PBP** and **IRR** parameters were taken into account**.** A **PBP** of **18.6** years was registered, much more than the loan **PBP** of 10 years considered while an insignificant **IRR** value of only **1%** was obtained**.**

Overall, for the sanitation system alternatives which consisted of the anaerobic digestion unit, the performance trends with reference to the **NPV** showed that the **INTEG 2** alternative performed best. This performance trend was attributed to high income due to additional revenue from briquette utilisation/sale and **GHG** emission reduction**.** Meanwhile, the performance trend with reference to the **PBP** and **IRR** showed that the **COMAPD LF** alternative performed best in comparison to other alternatives. This was attributed to the fact the alternative had reduced installation/investment costs due to the proposed utilisation of the existing composting plant at Mukono landfill instead of constructing a new plant**.**

9.8 Conclusion

The economic feasibility assessment of the sanitation system alternatives was carried out based on key assumptions and three key parameters, which included the net present value (**NPV**), payback period (**PBP**) and internal rate of return (**IRR**) were computed. Initially, the key assumptions considered included; equity capital of 30%, an interest rate of 10% with a loan payback period 10 years in addition to considering fugitive emissions from the anaerobic digester/biogas plant as 7% of the biogas produced. Taking into consideration these assumptions, variable sanitation system performance trends were registered with reference to the three parameters (**NPV, PBP** and **IRR**). During the assessment, two scenarios were considered for the sanitation system alternatives which consisted of an anaerobic digestion unit. These scenarios were utilisation of biogas generated directly for cooking purposes (**BfC**) and utilisation of the biogas produced for cogeneration (**CoGen**) of electricity and heat.

Taking into consideration the **CoGen** scenario while additionally incorporating the **Status Quo** system alternative, which does not consist of anaerobic digestion unit, the performance trend with reference to the **NPV** showed that the **INTEG 2** alternative performed best followed by **COMPAD LF**, **INTEG 1**, **COMPAD, INCAD** and finally the **Status Quo** alternative. The performance of the alternatives was influenced by the annual income accrued by the system alternatives. Thus, the higher the annual income, the better the system alternative performed. The good performance of the **INTEG 2** alternative in comparison to all other sanitation system alternatives was attributed to additional revenues accrued from greenhouse gas (**GHG**) emission reduction and sale of briquettes made from digestate.

For the same scenario (**CoGen**), the performance trend of the sanitation system alternatives with reference to the **PBP** and **IRR** showed that the **Status Quo** alternative performed best followed by the **COMPAD LF**, **INTEG 2**, **INTEG 1**, **COMPAD** and finally the **INCAD** alternative. Noteworthy was that for all alternatives, a **PBP** less than the 10 year loan period was registered. Meanwhile, the performance trend with reference to the **IRR** showed a similar trend to that of the **PBP** with the **Status Quo** alternative registering an **IRR** of at least 100%. While the remaining system alternatives registered **IRR** values ranging between 14-32%. The good performance of the **Status Quo** alternatives with reference to these two parameters was attributed to the fact that the main installation considered for the alternative included modifications to incorporate a roofing structure for the lagoons at **UCU** wastewater treatment plant. These modifications would boost drying of sewage sludge, especially during rainy seasons. Thus, with such low installation costs incurred and much higher income accrued due to health improvement benefits, the alternative performed significantly better than the remaining system alternatives.

Meanwhile, the better performance of the **COMPAD LF** alternative in comparison to the **INTEG 2**, **INTEG 1**, **COMPAD**, and **INCAD** alternatives was additionally attributed to the fact that the alternative had reduced investment costs. This was mainly because utilisation of the composting plant at Mukono Municipal landfill was proposed instead of installing a new composting unit. The overall economic feasibility performance trend taking into consideration all three parameters showed that **COMPAD LF>INTEG 2>Status Quo>INTEG 1>COMPAD>INCAD**.

With reference to the **BfC** scenario, all sanitation system alternatives except the **INCAD** alternative registered positive **NPVs**. The performance trend showed that the **INTEG 2** alternative still performed best followed by the **COMPAD LF**, **INTEG 1**, **COMPAD**, **Status Quo** and finally the **INCAD** alternative, which registered a negative **NPV**. As was the case for the **CoGen** scenario, the performance was influenced by the annual income accrued by the respective system alternatives. Thus, the higher the annual income, the better the system alternative performed with reference to **NPV**. Meanwhile, the negative **NPV** for the **INCAD** alternative was due to the much lower income accrued by the alternative in comparison to the overall investment of the system. Given that sewage sludge was incinerated in the **INCAD** alternative, the only resources accrued in the form of organic fertilizer or soil conditioner were mainly from the anaerobic digestion unit. As such, the overall annual income from the system alternatives was lower in comparison to other alternatives.

However, with reference to the **PBP** and **IRR**, the performance trend for the system alternatives showed a slight variation to that of CoGen scenario with the **INTEG 2** alternative performing better than **Status Quo** followed by **COMPAD LF, INTEG 1, COMPAD** and finally the **INCAD** alternative. Noteworthy was that higher **NPVs**, lower **PBPs** and higher **IRR** values were registered for the system alternatives when **CoGen** scenario was considered in comparison to when the **BfC** scenario was considered. These findings suggest that it may be additionally economically attractive to consider the **CoGen** scenario instead of the **BfC** scenario. Although such considerations would be based on the University`s priorities. Furthermore, an overall performance trend with reference to all three parameters showed **INTEG 2>Status Quo>COMPAD LF>INTEG 1>COMPAD>INCAD.** In this scenario, the **INTEG 2** and **Status Quo** alternatives performed better than the **COMPAD LF** alternative.

A sensitivity analysis to determine the influence of variation in assumptions to the economic feasibility of the sanitation system alternatives was carried out. The results showed that reduction of fugitive emissions from the anaerobic digester or biogas plant to 5% and later 3% positively influenced the **NPV**, **PBP** and **IRR** for all five alternatives. In comparison to the base case scenario where initial assumptions were considered, the **NPVs** increased by at least 7% while the **PBP** reduced by atleast 1 month and only a 2% increment in **IRR** was noted for all alternatives. Thus, reduction of fugitive emission significantly affected the **NPV** since more biogas would be available for cogeneration, which would in turn contribute to additional electricity and heat sales, accruing more annual income.

Adjustment of the interest rate to 12% while maintaining equity capital at 30% and fugitive emissions at 7% resulted in the reduction in **NPVs** by at least 27% for the **COMPAD**, **COMPAD LF, INTEG 1** and **INTEG 2** alternatives in comparison to the **NPVs** computed in the base case scenario. Meanwhile, the **INCAD** alternative registered a negative **NPV**. The trend of performance still showed that the **INTEG 2** alternative performed best followed by the **COMPAD LF**, **INTEG 1**and finally the **COMPAD** alternative. Moreover, with reference to the **PBP** and **IRR**, the **COMPAD LF** alternative performed better than the other alternatives. Adjusting the interest to 5% no doubt resulted in much higher **NPVs**, much lower **PBPs** and slightly higher **IRR** values for all sanitation system alternatives considered.

Reducing the equity capital to 20%showed reduced **NPVs**, increased **PBPs** and much lower **IRR** values as would be expected. Particularly, the **INCAD** alternative registered a negative **NPV**. Increasing the equity capital to 40% no doubt positively influenced the result for the sanitation system alternatives with significant increase in **NPVs** of at least **100%,** lower **PBPs** by up to 1year and higher **IRR** values by at least 6% in comparison to the base case scenario. Moreover, the **INCAD** alternative also registered a positive **NPV**. A final adjustment to check the influence on the results when no equity capital was considered showed that only the **INTEG 2** and **COMPAD LF** alternatives were feasible since they registered positive **NPVs** and **PBPs** registered were below 10 years while the **IRR** values were at least 15%. The **COMPAD**, **INCAD** and **INTEG 1** alternatives all registered negative **NPVs**, **IRR** values of less than 10% and **PBPs** ranging from 9.6 years to 18.6 years. Therefore, the sensitivity analysis highlighted key areas that could be considered in case of necessary adjustment for implementation of sanitation systems. Particularly in case the **CoGen** scenario was considered, then equity capital of at least 30%, an interest rate less than 10% and fugitive emissions less than 7 % would positively influence the economic feasibility of all the sanitation system alternatives which consisted of the anaerobic digestion unit.

The results from the economic feasibility assessment illuminated the fact that increased annual income partly influenced by increased revenue from resource recovery contributed to the good performance of sanitation systems. Moreover, reduced investment costs due to avoided installation costs/expenses also positively influenced the performance of the sanitation systems, case in point the **COMPAD LF** alternative. By considering the utilisation of an existing composting plant at Mukono landfill instead of constructing new facilities, the overall system investment costs were reduced. This in turn also contributed to the good performance of the **COMPAD LF** sanitation system as shown by the overall performance trends i.e **COMPAD LF>INTEG 2>Status Quo>INTEG 1>COMPAD>INCAD** for the **CoGen** scenario and **INTEG 2>Status Quo>COMPAD LF>INTEG 1>COMPAD>INCAD** for the **BfC** scenario

Similar to the environmental feasibility findings discussed in Chapter 8, the overall good performance to an integrated sanitation system depends on the resources recovered since this contributes to the overall annual income accrued. Moreover, sanitation systems which consider using already existing system components additionally perform well due to the avoided installation costs.

For instance, instead of installing a new incineration unit or composting plant, using existing plants would result in avoided installation costs. Such scenarios can be considered for cities and towns which may already have well-built incinerators. Moreover, collaboration with city and town authorities to use existing composting plants located in certain landfills within Uganda could positively influence the economic feasibility of integrated sanitation systems installed at housing estates, institutions or other private entities within urban areas. Of course, such collaborations should be clearly governed by supporting documents such as memoranda of understanding and contracts or agreements, which would clearly define roles and expectations of involved parties.

Besides, with reference to resource recovery in the form of biogas, further reduction in biogas leakage to at most 3% would imply more biogas is available for direct utilisation or cogeneration and this would contribute to increased annual revenue. The avoided environmental impact associated with utilisation of biogas generated from the management of organic waste streams is translated into returns from reduction in greenhouse gas (**GHG**) emissions. This implies that opportunities exist for integrated sanitation systems to be registered as Clean Development Mechanism (**CDM**) projects. These projects would receive Carbon Credits and the revenue obtained from the carbon offsets which in turn contribute to the economic feasibility of the sanitation systems. Moreover, identifying any additional financial incentives offered for related projects by the Government of Uganda through related ministries for Education, Health, Energy and Mineral Development, Water and Environment would additionally boost the economic feasibility of integrated sanitation systems.

With reference to digestate utilisation, an understanding of the priorities of the responsible entity would avail necessary information related to resource recovery and revenues accrued. This can be informed by a market survey for the potential by-products from the integrated sanitation systems (biogas, organic fertilizer, briquettes etc). For instance, in case housing estates or institutions are interested in utilisation of briquettes instead of charcoal, then resource recovery from digestate can be focused towards briquette making rather than use as organic fertilizer. On the other hand, if the sanitation system is located in a peri-urban area where there is available land for agriculture or if there is a high demand for soil conditioner/organic fertilizer from landscape business owners in the cities and towns, then the utilisation of digestate as organic fertilizer may be preferred.

The findings from the economic feasibility for **UCU** also highlight key aspects that can be generally considered in case of similar assessments for integrated sanitation systems for other entities. Firstly, an investment of equity capital of at least 30% would generally be required since this would imply that more sanitation system alternatives can be considered economically feasible. The absence of equity capital for investment may limit the number of integrated sanitation system options to select from. Moreover, considering an interest rate of up to 10% also implies that a broader list of integrated sanitation system options can be considered for comparison. This will in turn allow for flexibility in decision making regarding the sanitation system alternatives.

In the interest of reflecting changes in discounting due to time variations, a higher interest rate of about 12% could limit the number of sanitation system alternatives that are considered feasible. Nevertheless, variation in discount rates to incorporate a range of values should be considered with respect to the local conditions of a particular setting so that the *net present values*, *payback period* and *internal rate of return* referred to in the assessments will reflect any identified changes.

Secondly, the overall economic feasibility of integrated sanitation system alternatives will no doubt be influenced by the variable installation costs of components within sanitation systems. Often the case component supplier quotations will vary and variable considerations for components within the system may also exist, influencing overall costs. The latter can be expected, especially with reference to the anaerobic digestion units, which may have variable components for the pre-treatment and post treatment stages.

Moreover, other design considerations for the various components within the sanitation system may be taken into account and this would also influence the overall economic feasibility of the sanitation system. For instance, instead of using continuous stirred tank reactors which require energy to run the stirrers and monitoring systems, a simple fixed dome digester or non-agitated covered lagoons could be considered for housing estates or institutions etc. Such systems could to have reduced overall costs in comparison to stirred tank reactors and this would in turn influence their respective economic feasibility.

With reference to the scope and value chain considered for integrated sanitation systems, engagement of various actors/stakeholders is expected. Thus, socio-cultural aspects which are often influenced by culture are pertinent in guiding decisions related to system selection. Chapter 10 discusses the socio-cultural assessment of the sanitation system alternatives proposed for **UCU**.

10 Socio-Cultural Assessment of Sanitation System Alternatives

Chapter ***10*** *focuses of the socio-cultural assessment of the sanitation system alternatives proposed for* ***UCU****. A stakeholder analysis was carried out to identify and categorise relevant stakeholders. Thereafter, a survey to assess socio-cultural aspects related to the various sanitation system alternatives was carried out. This Chapter concludes with a review of the regulatory requirements relevant for the proposed sanitation systems.*

10.1 Socio-Cultural Aspects Relevant to Sanitation Systems

The socio-cultural assessment of sanitation system alternatives proposed for **UCU** took into consideration the acceptability of the sanitation systems. Moreover, reference to an enabling environment which was defined by the institutional and regulatory requirements was additionally considered. However, prior to determination of system acceptability and the enabling environment, identification of stakeholders involved, definition of their roles and interests as well as their interrelations was crucial. As such, a stakeholder analysis was carried out to further inform the socio-cultural assessment. The stakeholder analysis which consisted of three main phases i.e. context definition, application of stakeholder methods and actions taken is discussed (refer to Chapter 5).

10.2 Stakeholder Analysis for UCU

With reference to the phases of stakeholder analysis mentioned, the stakeholder analysis for **UCU** sought to identify the stakeholder groups with ''interest'' in and ''influence'' over the sanitation system alternatives proposed. Identification of stakeholders was carried out to enable solicitation of representative information from respective stakeholders regarding the sanitation system alternatives. Thus, the necessary feedback from the stakeholders provided the research context for the system alternatives and future recommendations for the respective systems. A sanitation system value chain discussed in Chapter 3 of this dissertation was considered to allow for structured analysis, which systematically assessed the main system components relevant for smooth operation of the respective sanitation alternatives. Three main components of the sanitation systems were considered i.e. substrate or input component, technology combinations (anaerobic digestion plus other technologies) and product chain component.

Substrate chain component considered the sources, quantities and qualities of inputs or substrate managed or proposed for the respective system alternatives. Moreover, variations in waste stream generation, especially during semester breaks at **UCU** were taken into account. Proposed collection and transportation, particularly of cow dung and faecal sludge from the University Farm and Mukono Municipality was also considered in this component (refer to Chapter 6).

Technology combinations component examined the combination of anaerobic digestion with other technologies i.e. incineration, composting and solar drying for the management of organic waste streams. With reference to the current sanitation system in operation at **UCU**, the suggested further management and disposal of sewage sludge at Lubigi or Bugolobi Wastewater Treatment Plants was taken into consideration.

Product chain component took into consideration the proposed mode of biogas utilisation, factoring in the distance between the anaerobic digester location and final utilisation points. More than that, the proposed utilisation of briquettes made from digestate as well as compost and digestate as organic fertilizer were taken into account.
An overview of the stakeholders identified, their roles, interests and level of power in relation to sanitation system alternatives is later shown in Figure 10-1. Having already defined the context of the sanitation systems in the previous chapters, the following sections focused on the application of stakeholder methods and actions.

10.2.1 Application of Stakeholder Methods

Stakeholder identification with reference to the **UCU** scenario was an iterative process that drew on the rich variety of methods, which included obtaining expert opinion, use of semi-structured interviews, snowball sampling, detailed literature review and key informant consultations (Adams 2007). Particularly with reference to the `snowball` technique, at the end of each key informant interview, respondents were asked to identify other important stakeholders who would or could have considerable influence with regards to the **Integrated Sanitation System Approach** proposed for **UCU**. In addition to the snowballing technique applied, reference was made to the sanitation system alternatives proposed for **UCU** and this led to the development of a comprehensive list of stakeholders. For the respective system alternatives proposed for **UCU**, stakeholders were identified and characterised under categories.

Differentiation and Categorisation of Stakeholders

To ensure no relevant stakeholder was forgotten in the process, a broad category list was considered i.e.

- Funding agency
- Relevant government authorities
- Organic waste generators
- System design and installation specialists
- Future operation and maintenance staff
- End-users of products from sanitation system
- Legislator and enforcement agencies
- Technical/research institutes
- National and international NGOs
- Sanitation system users
- Power grid operators/legislators
- Other benefactors

For each of the stakeholders identified within the categories, an assessment of their respective roles and their influence with reference to the sanitation system alternatives was carried out as summarised later in Table 10-1.

10.2.2 Relationship between Stakeholders

Once the stakeholders were differentiated and categorised, establishment of their respective influence with reference to the sanitation system alternatives was carried out. Ultimately, ***influence*** in this context refers to the power stakeholders have over a project or area of concern and this controls the decisions made, facilitates project implementation or exerts influence that affects the project negatively. Concurrently, examination of the importance of the respective stakeholders with reference to the sanitation system alternatives was accomplished.

Importance refers to the priority given by an intervention agency (e.g. donor, government, project, farmer organisation) to satisfy the stakeholders' needs and interests. ***Importance*** is distinct from ***influence*** in that an agency may place great priority on a project and might be considered important but have a very limited power to ***influence*** key decisions (Lohri et al. 2013; Reed et al. 2009; Hermans and Taketa 2006). The stakeholder interests were reflected as their respective positions towards the sanitation systems and defined as supportive, neutral or disruptive. On the other hand the ***importance*** and ***influence*** of the stakeholders was defined as low, medium or high. Rating of ***Importance*** and ***influence/power*** of respective stakeholders was carried out by the researcher based on additional input from key informants during stakeholder consultation.

The ***Importance–Power*** matrix, which basically gave on overview of the stakeholder relationships, also reflected on the significance of stakeholders. Furthermore, the matrix exposed the key stakeholders from whom additional information relevant to the socio-cultural aspects was attained. Table 10-1 gives a summary of the stakeholder assessment, while Figure 10-1 represents the ***Importance-Power*** matrix for the stakeholders identified.

Table 10-1: Summary of Stakeholder Assessment for UCU

Stakeholder Category	Specific Entities	Role	Power/influence	Importance	Position
Funding agency	• **UCU** • Banks	• Avail portion of funding for sanitation system investment • Source of additional funding for investment through loans	• High • Low	• High • Low	• Supportive • Supportive
Government authorities	• Ministry of Water & Environment(MoWE) • Ministry of Energy and Mineral Development (Renewable Energy Department MEMD) • Ministry of Education and Sports(MoES) • Ministry of Health(MoH)	• Clear communication of relevant national policies, standards and regulations • Offer guidance and where necessary, incentives with reference to government plans	• Low	• High	• Supportive
Organic Waste generators	• **UCU** • Mukono- Municipality • Diary farmer- **UCU** farm	• Supply sewage sludge and potential source of kitchen waste • Supply faecal sludge • Supply cow dung	• High • Low • Low	• High • Low • High	• Supportive • Supportive • Supportive
System design & installation specialists	• Contractors	• Design and install sanitation systems	• Low	• High	• Supportive
Future Operation & maintainance staff	• **UCU** staff • External support	• Maintenance and operation of sanitation systems	• High • Low	• High • High	• Supportive • Supportive

End user of products from sanitation systems	• **UCU** • Interested Farmers	• Utilisation of biogas and compost as soil conditioner • Purchase of compost or digestate as organic fertilizer	• High • Low	• High • High	• Supportive • Supportive
Legislators/ enforcement	• **NWSC** • **NEMA** • Power grid operators/regulators • Local authorities at Mukono municipality	• Give approval where necessary(sewage sludge reuse or disposal) • Check compliance with national regulations related to waste management (discharge standards, emission checks etc.) • Offer technical support to check compliance	• High • High • Low	• High • Low • Low	• Neutral • Neutral • Neutral
Technical, research institutes or NGO`s	• **GIZ** • **WFP**	• Avail necessary support in form of research and advice from experiences on biogas production and faecal sludge management	• Low	• Low	• Supportive
Sanitation system Users	• **UCU**(students, staff and visitors)	• Use sanitation system	• High	• High	• Supportive
Other benefactors	• Local farmers within Mukono area	• Currently utilising kitchen waste as animal feed	• Low	• Low	• Disruptive

Source: Author

Where;
GIZ; Deutsche Gesellschaft für Internationale Zusammenarbeit-Uganda
NWSC; National Water & Sewerage Corporation
NEMA; National Environment Management Authority
WFP; Water for the People-Uganda

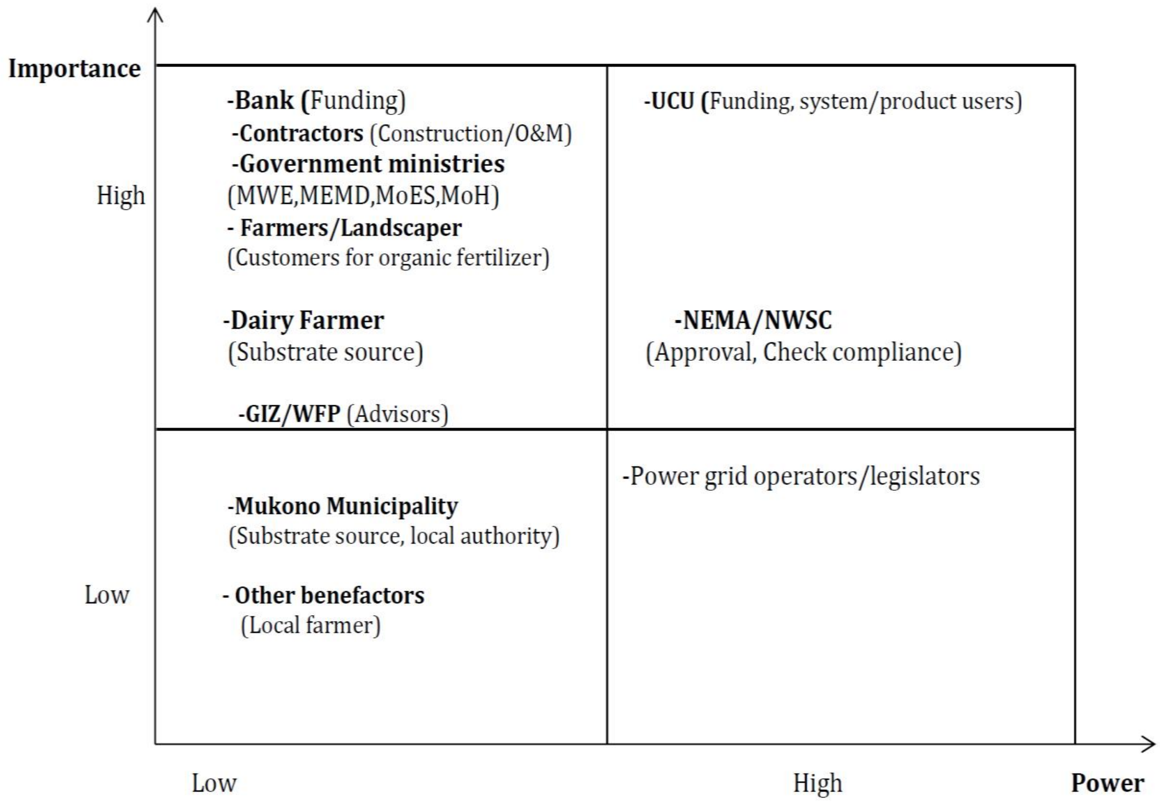

Figure 10-1: Importance-Power Matrix for Stakeholders at UCU
Source: Author

The ***Importance-Power*** matrix presented in Figure 10-1 showed that regulatory bodies i.e. **NEMA, NWSC** were considered to have high *power/influence* since implementation of the proposed sanitation systems would be based on their approval. Prior to such project implementation, an environmental impact assessment is mandatory and the approval of the related project would be given by **NEMA** (NEMA 1995). In collaboration with entities such as **NWSC,** which is mandated to manage wastewater/sewerage, **NEMA** receives necessary guidance for approval of sanitation system projects. Moreover, during the operation stage of such projects or facilities, the same entities are mandated to check compliance with conditions of approval initially stated. Thus, a high level of *importance* with reference to the proposed sanitation system sustainability was registered for **NEMA** and **NWSC.**

Meanwhile, in case **UCU** opted for cogeneration of electricity and heat from the biogas produced from a selected sanitation system alternative, then permission to supply power to the power grid would be required. As such, the power grid operators/legislators would be required to give the necessary approval and this explains the high *level of power* accorded to this stakeholder group. Nevertheless, their level of *importance* with regards to the sanitation systems was generally considered to be low and since these entities would mainly offer an approval/regulatory service, their input was considered to be neutral.

With reference to government ministries i.e. **MWE, MEMD, MoES, MoH**, a high level of importance was registered mainly because these entities ensure that necessary regulations, policies and standards are in place to guide the potential implementation of related projects. Moreover, information related to potential incentives offered by the government could also be obtained from the respective ministries. Despite a high level of importance attached these entities, the ministries generally have low influence on the potential implementation of the proposed sanitation systems. This is because duties related to enforcement of the regulatory requirements are devolved to entities such as **NEMA** and **NWSC**. Nevertheless, by ensuring that the necessary regulatory framework is in place and information related to incentives is availed, the ministries provide an enabling environment, which is reflected as a supportive position. On the other hand, entities such as **NEMA** and **NWSC** hold a neutral position since they approve and check compliance to available regulations, standards and policies.

With regards to the substrates sources i.e. dairy farmer operating the **UCU** farm and Mukono municipality as a potential source of faecal sludge, low level of *power/influence* over the proposed sanitation systems was recorded. While high *importance* was attached to the dairy farmer and low level of *importance* to Mukono Municipality respectively. The variation in level of *importance* attached to the respective stakeholder groups was due to the fact that cow dung from the dairy farm was considered a main substrate while faecal sludge from the municipality was considered an additional substrate.

Moreover, the potential treatment and or management of the faecal sludge would be based on individual customer interest in managing the faecal sludge and also the willingness/capacity of **UCU** to offer the service. Although the **WWTP** at **UCU** currently operates at half its capacity i.e. **160m^3/day** instead of **320m^3/day**, increase in population at the University could imply that the **WWTP** would operate at full capacity. This would therefore reduce the possibility of additionally managing faecal sludge at the **WWTP**. Although the dairy farm and Mukono Municipality are potential sources of substrate for the proposed sanitation systems, both stakeholders were considered to have low *power/influence* with reference to the proposed sanitation systems. This was mainly because other key substrates i.e. sewage sludge and kitchen waste could still be obtained from the University. The mere fact that both the dairy farmer and Mukono municipality were considered potential sources of substrate implied that the respective stakeholder groups offer a supportive position.

Noteworthy was that the local farmers (other benefactors) neighbouring **UCU** currently utilise kitchen waste as animal feed and were also considered to have low *power* and *importance*. The fact that the farmers obtain the kitchen waste freely based on a mutual understanding with kitchen administration implied that they have little say in case **UCU** decided to utilise own waste for other purpose. However, the position held by these farmers could be disruptive in case a smooth transition to the proposed waste utilisation mode is not considered.

The contractors who would offer construction, operation and maintenance services were generally considered to have low *power/influence* with reference to the proposed sanitation systems. Nevertheless, a high level of *importance* was attached to the contractors since the services that would be offered at various stages i.e. construction and maintenance would be crucial to the existence of the proposed sanitation systems.

With regards to NGO`s such as **GIZ** and **WFP,** low level of *power* and high level of *importance* was registered. By offering the necessary advice based on experiences, operation and maintenance of the proposed sanitation system would be ensured or boosted. This would then reflect the importance of the advisory role from NGO`s towards the success of the proposed sanitation systems. Despite the *importance* of the advisory role played by NGO`s, their overall *power/influence* on the proposed sanitation systems was considered to be low. Based on this background, the **NGO`s** were considered to be supportive of the proposed sanitation systems.

In terms of availing additional funding**,** banks which would be the source of loans were considered to have low *power* with regards to the respective project planning although the funds offered would be highly *important* for system implementation. Thus, the banks were considered to have a supportive position towards the proposed sanitation systems. Furthermore, farmers/landscapers who would purchase compost/digestate as organic fertilizer were considered to be highly *important* since their remittances would be sources of income for **UCU**.

However, the *power* wielded by the farmers and landscapers was considered to be low since they would not have direct influence on various activities carried out at the different phases of the proposed sanitation systems. As such, an overall supportive position was cited for the farmers/landscapers. **UCU** on the other hand registered high level of *power* and *importance* because in addition to being the main beneficiary of system byproducts (biogas and briquettes), a portion of funding for the proposed sanitation system planning and implementation would be availed by the University (refer to Chapter 9). Moreover, the University would be the main users of the sanitation system installed and necessary operation of the sanitation system would be accomplished by support staff employed at **UCU.** Hence, **UCU** was considered to hold an overall supportive position with regards to the proposed sanitation systems. With reference to the stakeholder analysis and ***Importance-Power*** matrix, key areas for possible improvement were identified as discussed.

10.2.3 Recommendations for Improvement

Overall, the ***Importance-Power*** matrix clearly highlighted **UCU`s** position with regards to the proposed sanitation systems. Furthermore, the significant roles and interests of regulatory bodies, government entities and other stakeholders were illuminated. Therefore, key recommendations derived from the matrix include;

- Clear identification of relevant regulations, standards and policies to ensure compliance so that necessary approval from entities such as **NEMA** and **NWSC** is easily obtained.
- Continuous consultation with relevant government ministries through the different stages of the chosen sanitation system is recommended for compliance purposes and exploitation of additional benefits in the form of incentives.
- **UCU** should consider collaborating with entities such as **GIZ** and **WFP** since relevant advice offered could result in improved system efficiency and management of byproducts from the sanitation systems. Hence, based on advice/experience from the different NGO`s, certain challenges or limitations related to respective sanitation systems could be avoided and this could boost system performance while ensuring additional cost saving. Furthermore, collaborations with these entities could result in additional research in related topics areas, which is much needed in the country.
- With regards to provision of additional substrate by stakeholders such as the dairy farmer at **UCU** farm and potential suppliers of faecal sludge from Mukono Municipality, contracts should be drawn or Memorandum of Understanding (MoUs) should be signed. This would ensure clarity and continuity of substrate supply while guarantying that required quantities from the respective sources are availed. Moreover, any other expectations from both parties i.e. **UCU** and substrate provider in the form of fees charged or quality assurance considerations can be included in the contracts or **MoUs,** simplifying collaboration.
- Despite **UCU** currently offering the local farmers kitchen waste freely, the kitchen administration should consider holding discussions with the farmers prior to channeling the waste as a substrate for the sanitation systems. Failure to do so could result in local farmers playing a disruptive role to the overall interest of the proposed sanitation systems. Offering a portion of the kitchen waste i.e. food peelings to the local farmers could be considered to entice the local farmers and ensure smooth transition.
- To ensure available market for the compost and digestate as organic fertilizer, **UCU** should consider investing in informative advertising to attract farmers and landscapers to purchase the sanitation system byproducts. Moreover, obtaining support from relevant entities such as **NWSC** who are already producing and selling soil conditioner from similar organic waste streams could further boost compost sales.
- Furthermore, continuous interaction with compost and digestate customers should be considered once sanitation systems are implemented and operational. This would ensure that customer feedback regarding the quality of compost is taken into account and could give **UCU** an added advantage over potential competitors.

In conclusion, the stakeholder analysis carried out availed necessary information on the significance of stakeholders, their relationships and possible points of action to be considered. Having identified the role and significance of **UCU** as a primary stakeholder, elicitation of socio-cultural views related to the proposed sanitation system alternatives was deemed necessary. As such, a stakeholder survey was conducted.

10.2.4 UCU Stakeholder Survey

A survey generally consists of 7 steps, which include; (1) design, (2) writing questions, (3) carrying out pilot survey, (4) administering the survey, (5)data entry, (6)analysis and (7) and finally reporting of findings (Adams 2007; Lancaster 2004). The Survey design***;*** defines the survey purpose, sample selection and the method of delivery (Lancaster 2004; Mathers et al. 2007). The overall goal of the survey carried out at **UCU** was to elicit stakeholder response regarding the socio-cultural aspects related to the proposed sanitation system alternatives. Overall, acceptability of the sanitation system alternatives was examined based on stakeholder willingness to utilise byproducts from system alternatives and level of convenience attached to system alternatives among others.

Selection of the survey sample was informed by the stakeholder analysis, which confirmed the significant role played by **UCU** with reference to the proposed sanitation system alternatives. Considering that for the sustainability of a sanitation system, user involvement was crucial, the survey focused on eliciting views from mainly students at **UCU** although other teaching and non-teaching staff members also participated in the survey. The decision to focus on student opinion during the survey was influenced by the fact that students accounted for more than half the population at the University thus, were bound to be affected by any impacts related to the proposed sanitation system alternatives. Moreover, students would be the main beneficiaries of the kitchen services and other energy supply, in addition to improved sanitation at **UCU** that would be accrued from the sanitation systems.

Based on the records from the security office at **UCU** (May-August 2016)**,** an overall population of 4,000 people who included students (both resident and non-residents), staff members and visitors was registered. Although the overall population estimate of the University is 6,000(refer to Chapter 1), the value 4,000 was considered for the survey because it reflected the exact number of people within the University on a daily basis in the specified duration. Thus, in addition to the population size, a 5% margin of error and 95% confidence level were used to compute the required sample size for the survey with reference to Equation 10-1 (Desu and Raghavarao 1990; Mathers et al. 2007).

$$SS = \frac{Z^2 * (p) * (1-p)}{c^2}$$ ……………………………………………………………Equation 10-1

Where Z= Z value (e.g. 1.96 for 95% confidence level), p= standard deviation, **C**= confidence interval or margin of error and **SS** represents the sample size. Once the sample size was computed, the correction for finite population was computed with reference to Equation 10-2 (Desu and Raghavarao 1990).

$$Corrected\ sample\ size = \frac{SS * P}{P + SS - 1} \text{ .... Equation 10-2}$$

Where **SS** is the initial sample size and **P** is the finite population

Thus, with reference to equations10-1 and 10-2 and taking into consideration a margin of error of 5% and 95% confidence level, a corrected sample size of **351** people was computed for the survey at **UCU.** Structured questionnaires were designed and used to solicit the required information from the respondents during the survey and a copy of the questionnaire is included in Appendix 5. Survey trials were conducted in September 2016 and this allowed for necessary adjustments to be made on the questionnaires prior to the actual survey. 351 corrected questionnaires were then randomly availed to the various respondents and collected once completed by research assistants. In few instances, the questionnaires were filled out with the help of research assistants during question- answer sessions with respondents. The actual survey was administered over a period of 3 months i.e. from October to December 2016 and the results obtained are summarised in Section10.2.5.

10.2.5 Survey Results for UCU

From the distributed questionnaires (**351)**, response from **300** respondents was obtained thus, a response rate of at least 85% was recorded. This response rate was considered much more representative than the low expectation of 20% accepted in most surveys. Ultimately, students constituted the majority of respondents, accounting for 96% while only 4% of the respondents were staff from **UCU.** Of the staff who responded to the survey**,** trainees/interns and teaching staff accounted for atleast 3% while the remaining 1% represented non-teaching staff. Consideration of more student respondents was by design since the students constituted more than half the population at the University i.e. resident and non-resident students. Moreover, students were also the main benefactors of the kitchen/dinning services, which could be influenced by utilisation of biogas generated from sanitation system proposed. In terms of gender representation, 43% of the respondents were female and the remaining 57% were male.

The survey examined the level of satisfaction of the respondent with regards to the current organic waste management at **UCU.** Results showed that only 26% of the respondents thought the current organic waste management system did not require further improvement. These respondents argued that they had not heard of complications experienced during operation of the current sanitation system. Moreover, some of these respondents also cited a possible challenge related to limited space within the University campus to cater for any additional improvements or system expansion. As such, the respondents argued that since no major complications had been identified with reference to the current system i.e., the **Status Quo** alternative, no improvements were necessary.

The remaining 74% of the respondents argued that the current organic waste sanitation system was insufficient and could be improved. These respondents mainly asserted that resource recovery from the sanitation system in the form of biogas could be achieved hence, the need for improvement. Their arguments were also backed up by the assertion that the population at **UCU** was growing and related improvements in sanitation management would be necessary. Moreover, other respondents thought that the University deserved to improve its sanitation management measures to reflect her status as a University of excellence in the country. Generally, these results concurred with the core aspects that inspired this research, i.e. improvement of organic waste management at **UCU** to adapt a sustainable sanitation approach, which incorporates resource recovery.

In achieving the overall survey goal i.e. assessment of sanitation system acceptability, *perception* towards the proposed system alternatives and *convenience* attached to systems were assessed. *Perception* which basically reflected emotional response towards the sanitation systems was defined by the *willingness to utilise compost, digestate, biogas and briquettes* from the respective system alternatives. While the potential impacts associated with the sanitation system alternatives such as noise, odor and other anticipated disturbances contributed to the level of *convenience* attached to the respective system alternatives. A summary of the survey results for the respective sanitation system alternatives is shown in Table 10-2.

Table 10-2: Summary of Willingness and Attitude towards Recovered Resource Utilisation

Parameters assessed	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Willingness to utilise compost from sewage sludge	87%	87%			
Willingness to utilise digestate(**Cd:Fw 30:70** substrate) as organic fertilizer	91%	91%	91%		
Attitude towards utilisation of biogas (from **Cd:Fw 30:70** substrate) directly for cooking purposes	68%-Agreed 26%-Uncertain 6%-Disagreed	68%-Agreed 26%-Uncertain 6%-Disagreed	68%-Agreed 26%-Uncertain 6%-Disagreed		
Preference of composting sanitation system alternatives	45%	55%			
Willingness to utilise digestate from **INTEG 1**(**Os:Cd:Fw 30:20:50**) as organic fertilizer				86%	
Attitude towards utilisation of biogas from **INTEG 1** directly for cooking purposes				75%-Agreed 19%-Uncertain 6%-Disagreed	
Willingness to utilise digestate from **INTEG 2(Fs:Os:Cd:Fw 10:20:20:50)** as organic fertilizer					59%
Willingness to utilise briquettes made from digestate(**INTEG 2**) for cooking purposes					64%
Attitude towards utilisation of biogas from **INTEG 2** directly for cooking purposes					52%-Agreed 34%-Uncertain 14%-Disagreed
Overall preferred biogas utilisation mode	CoGen- 60% Cooking-40%	CoGen- 60% Cooking-40%	CoGen- 60% Cooking-40%	CoGen- 60% Cooking-40%	CoGen- 60% Cooking-40%

Source: Survey **UCU**

CoGen- Cogeneration of electricity and heat from **CHP** unit

Note: The similar response for utilisation of biogas and digestate for **INCAD, COMPAD COMPAD LF** alternatives is due to the similar composition of substrates considered for the anaerobic digestion units of the system alternatives (Refer to system designs in Chapter 7)

10.2.5.1 Discussion of Survey Results

The survey results summarised in Table 10-2 showed that 87% of the respondents were willing to utilise compost generated from co-composting sewage sludge and organic waste. The remnant 13% of the respondents were uncomfortable with the proposal to utilise compost generated from **COMPAD** and **COMPAD LF** alternatives, citing the possibility of exposure to pathogens from using the compost. Respondents were concerned that potential users of the compost could still be exposed to pathogens during handling and use of the compost generated from sewage sludge and organic waste. On the other hand, 91% of the respondents indicated willingness to utilise the digestate from anaerobic digestion of cow dung (**Cd**) and food waste (**Fw**) (**Cd:Fw 30:70**) as organic fertilizer. The 4% increase in willingness to utilise digestate as organic fertilizer in comparison to compost as soil conditioner was attributed to the level of safety anticipated with utilising the digestate. The respondents perceived that much less pathogenic content would exist in the digestate because of the substrates used in the anaerobic digestion process.

The assessment of respondents' attitude towards utilisation of biogas from anaerobic digestion of **Cd:Fw 30:70** showed that 68% of the respondents agreed they would utilise the biogas directly for cooking. 26% of the respondents were uncertain if they could use the biogas generated for cooking purposes while the remaining 6% of the respondents noted that they would not use the biogas generated from cooking purposes. Both respondent groups who registered uncertainty and disagreement in utilisation of biogas for cooking mainly attributed their reservations to discomfort in utilising energy from animal faecal matter for cooking purposes. The respondents' attitude was influenced by their perception, which was based on cultural beliefs that *"waste should not be combined or used for food preparation so as to prevent any contamination, especially in the form of bad smell or odour".*

Similar perceptions were cited in an assessment of socio-cultural acceptability for biogas fuel utilisation from small-scale biogas digesters in Uganda under a **DFID**[20] project. The general feeling was that "*it was not right to utilise gas from human waste for cooking"*, even though human waste was not recognisable in the slurry (DFID 2011). Meanwhile, the respondents who responded positively to utilisation of biogas for cooking purposes perceived the biogas generated as a cleaner energy source and had no qualms utilising it for cooking purposes. Most of these respondents reasoned that utilisation of biogas from animal and human faecal matter was no longer a new phenomenon and cited knowledge of biogas digester application mainly at domestic or farm level. Their argument further confirms that beliefs and perceptions are subject to change, especially through sensitisation and raising awareness, which have been seen as enabling tools in most sanitation interventions (Peal et al. 2010; Lüthi et al. 2011b)

[20] DFID: Department for international Development

A preferential assessment of the **COMPAD** and **COMPAD LF** alternatives showed that 55% of the respondents preferred **COMPAD LF** to **COMPAD** alternative**.** The respondents argued that limited exposure to related impacts would be expected in case **COMPAD LF** was opted for in comparison to the **COMPAD** alternative. The respondents also pointed out that odour from composting of sewages sludge and organic waste as well as noise nuisances related to process operation such as mixing and shifting piles etc., would be limited to the staff at Mukono Municipal landfill instead of **UCU** staff and community at large. Nevertheless, 45% of the respondents who preferred the **COMPAD** alternative reasoned that **UCU** would be saved from additional costs for hiring workers and transportation of sewage sludge to the landfill composting unit, which is located 7km away from the campus. The respondents also asserted that necessary measures would be put in place to limit impacts related to noise and odor from the proposed system processes.

Concerning the willingness to utilise digestate from anaerobic digestion of sewage sludge (**Os**), cow dung and food waste (**Os:Cd:Fw 30:20:50**) proposed for the **INTEG 1** alternative, 86% of the respondents responded positively. The main reasons for their positive response included; *reduced costs of digestate as organic fertilizer in comparison to artificial fertilizer, high nutrient content in organic fertilizer easily taken up by the soils, availability of the organic fertilizer and less anticipated toxicity in organic fertilizer in comparison to artificial fertilizer*. While 14% of the respondents indicated unwillingness to utilise the digestate as organic fertilizer and cited the following reasons for their decision; *health risks to users due possible exposure to pathogens, low nutrient content of organic fertilizer in comparison to artificial fertilizer and bad odour of fertilizer associated with substrates used*.

The survey results also showed that an additional 5% of the respondents were reluctant to utilise digestate from **INTEG 1** alternative compared to digestate from **COMPAD, COMPAD LF** and **INCAD** alternatives. This response was attributed to respondents' perception towards utilisation of digestate produced from a substrate mix consisting of sewage sludge as already discussed. Interestingly, the results also showed that 75% of the respondents would consider utilising biogas generated from **INTEG 1** alternative for cooking while 19% of the respondents were uncertain and 6% of the respondents totally disagreed. In comparison with the findings related to attitude towards utilisation of biogas generated from the anaerobic digestion of **Cd:Fw 30:70**, an additional 7% of the respondents were willing to utilise the biogas generated for cooking, despite sewage sludge being one of the substrates used in **INTEG 1** alternative**.**

Meanwhile, only 59% of respondents were willing to utilise the digestate from anaerobic digestion of faecal sludge(Fs), cow dung, food waste and sewage sludge i.e. **INTEG 2** (**Fs:Os:Cd:Fw 10:20:20:50**) as organic fertilizer. The overall notion that the addition of faecal sludge in the substrate mix would additionally expose users to health risks influenced the drop in willingness to utilise the digestate as fertilizer from 86% for **INTEG 1**to 59% for **INTEG 2** alternative.

Worthy of mention was that 64% of the respondents also indicated their willingness to utilise briquettes made from digestate for cooking purposes. The respondents argued that *utilisation of briquettes would reduce dependence on charcoal and firewood for cooking, which would eventually reduce deforestation*. Moreover, the respondents also argued that *briquettes were a cheaper and more reliable option in comparison to charcoal and firewood due to the availability of resources i.e. digestate for making the briquettes*. The anticipated *higher energy content from briquettes in comparison to charcoal was also cited as one of the reasons for its preference*. The remaining 36% of the respondents who had reservations towards briquette utilisation attributed their decision to; *reluctance in utilising energy sources generated from faecal matter, possibility of unpleasant smell from briquettes and the that briquetting of digestate could be a labor intensive task*.

The respondents' attitude towards utilisation of biogas from **INTEG 2** alternative for cooking purposes registered lower values than when **INTEG 1** alternative was considered since 52% of the respondents were in agreement, 34% were uncertain while 14% totally disagreed. The overall concern regarding the possible contamination of food by biogas generated from the anaerobic digestion of substrates such as faecal and sewage sludge influenced the uncertainty and disagreement responses registered. Overall, 60% of the respondents' preferred that the biogas generated from system alternatives be used for cogeneration of electricity and heat instead of direct utilisation for cooking purposes. The main reason cited for this decision was the concern of food contamination, especially since biogas would be generated from faecal substrates. Interestingly, the findings from the environmental feasibility assessment discussed in Chapter 8 showed otherwise with preference of biogas for cooking rather than cogeneration resulting in less environmental burden for respective sanitation system alternatives.

The survey respondents were then asked to rank the sanitation system alternatives based on anticipated impacts such as odor and noise which were considered to contribute to the level of convenience attached. The ranking considered **1** as the least and **6** the highest level of noise or odour anticipated from the respective sanitation system alternatives. With regards to noise impact, results showed the best performance was anticipated from **INTEG 2** followed by **Status Quo, COMPAD LF** with a score of 2 followed by **COMPAD and INCAD** and finally **INTEG 1** alternative with a score of 5. The results for anticipated odour impact showed that **INTEG 2** alternative still performed best recording a score of 1 followed by **COMPAD**, **COMPAD LF**, **INCAD** at a score 4 and finally **INTEG 1** and **Status Quo** alternatives at a score 5 as shown in Figure 10-2. The variation in scores awarded for the respective sanitation systems was attributed to anticipated impact from the corresponding processes/technologies for system alternatives.

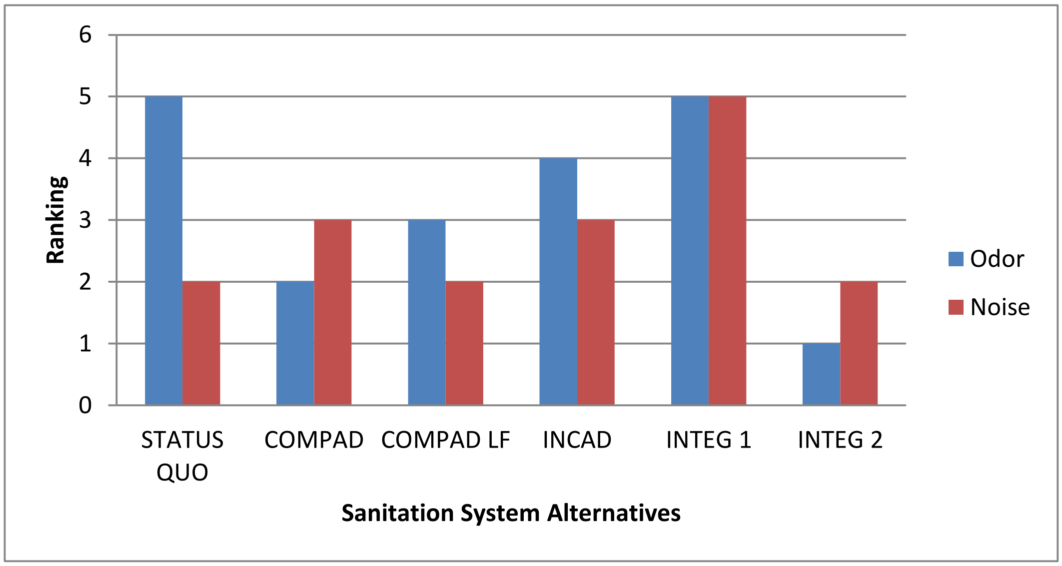

Figure 10-2: Odor and Noise Impact Ranking for Sanitation System Alternatives
Source: **UCU** stakeholder survey

An overall assessment of the *level of convenience* attached to the respective sanitation system and system *acceptability* was carried out based on a ranking scale where 1 represented the least and 6 represented the highest levels. The response showed that both **INTEG 1** and **INTEG 2** alternatives were considered least *convenient* and *acceptable*. **INCAD** alternative was also ranked as less convenient with a score of 2 although its overall acceptability was high at a score of 5. The **COMPAD** and **COMPAD LF** alternatives closely followed the **INCAD** alternative and registered a *convenience level* and *system acceptability* of 3. Finally, the **Status Quo** alternative registered the highest score with regards to the *level of convenience* at score of 4 and *an acceptability* score of 5. Figure 10-3 shows the overall response related to *level of convenience* and *acceptability* attached to the respective system alternatives.

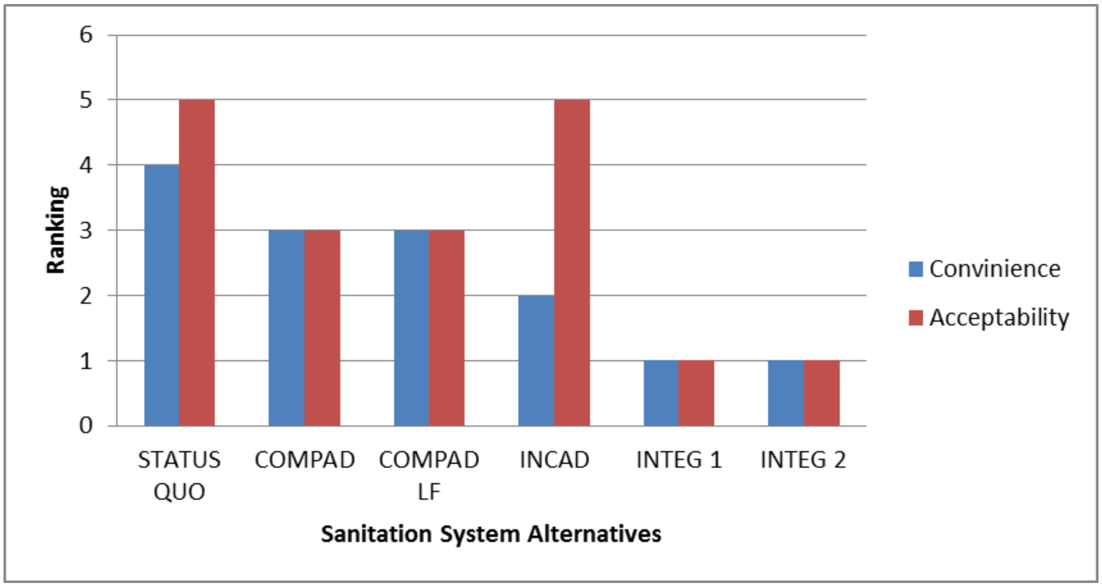

Figure 10-3: Level of Convenience and Acceptability Ranking of System Alternatives
Source: **UCU** Stakeholder Survey

In terms of *level of convenience* and *system acceptability*, the poor results of **INTEG 1** and **INTEG 2** alternatives in comparison to results for other alternatives was attributed to the reluctance to utilise products from the respective systems. Concerns of health risk due to pathogen exposure and possible contamination of food from utilisation of digestate as fertilizer and biogas for cooking purposes contributed to the low performance noted for **INTEG 1** and **INTEG 2** alternatives**.** The high *acceptability* of **INCAD** alternative was attributed to the fact that limited handling of sewage sludge would be expected in case co-incineration with medical or other waste was considered. While the high *acceptability* of the **Status Quo** alternative was attributed to secluded management of sewage sludge from **UCU** lagoon at other locations. The assumption that limited exposure of personnel to related impacts of odour, noise and health risks in case of further management and disposal of sewage sludge at Lubigi or Bugolobi treatment plants influenced the high acceptability of **Status Quo** alternative.

In spite of the respondents' reservations towards systems alternatives based on concerns of health risks from pathogen exposure and contamination of food among others, the sanitation system alternatives were designed bearing these concerns in mind. Hence, additional processes such as storage of compost and digestate prior to utilisation and solar drying of digestate prior to utilisation as organic fertilizer were included in the system designs to cater for any concerns related to health risks.

10.2.5.2 Recommendations Based on Survey

Reflecting on the key concerns raised in relation to willingness to utilise digestate or compost, it is recommended that in case of system implementation, **UCU s**hould liaise with entities such as **NWSC,** which is currently involved in the sale of conditioner from treated faecal and sewage sludge. Moreover, reference to regional compliance standard i.e **EPA** standards and Directive **86/278/EEC** for biosolid/sewage sludge application on land can be considered since Uganda currently does not have these standards. Reference to regional standards mentioned to help check the quality of digestate as fertilizer and compost would further guarantee potential use of products and acceptability of the respective system alternatives. With regards to reluctance to utilise biogas from the respective sanitation systems for cooking purposes, sensitisation of the stakeholders within **UCU** to raise awareness would probably improve the overall attitude and influence acceptability. Raising awareness on biogas utilisation and potential would be necessary since low awareness has long been cited among the socio-economic factors limiting biogas adoption in Uganda and Sub-Saharan Africa at large (Mwirigi et al. 2014). Raising awareness could be achieved by including educative articles in the University newspaper, carrying out demonstrative research and putting up posters in strategic locations i.e. department notice boards among others.

Furthermore, sensitisation of stakeholders with regards to compost and digestate utilisation should also be carried out to improve the willingness to utilise these products from respective sanitation systems. Moreover, through raising awareness, other practices such as source separation of waste could also be encouraged within **UCU** and this would boost the organic waste quantities eventually managed in the sanitation system alternatives.

UCU as an institution of higher learning offers the necessary platform for which collaborative research in key areas of interest can be carried. Research programmes focusing on expounding knowledge related to sanitation systems, resource recovery and economic benefits in addition to pathogen reduction in compost and digestate could be carried out. This could have a multiplier effect in disseminating the much required knowledge related to integrated sanitation systems. Moreover, by installing pilot scale/demonstration sanitation system units, in depth knowledge and necessary practical experiences could be attained while additionally raising awareness.

The survey findings also highlighted that separate management of waste streams was still favored as shown by the high *level of convenience* and *acceptability* accorded to the **Status Quo** alternative**.** This could be vaguely interpreted as the absence of a real problem with the existing sanitation system, especially if further management of sewage sludge is ignored. Moreover, the challenge of dependence on firewood for cooking purposes would still be eminent, especially if no alternate clean energy sources are considered. Therefore, raising awareness while highlighting the potential additional benefits in the form of resource recovery and improved sanitation would be crucial in influencing the *acceptability* of integrated sanitation system alternatives.

As already pointed out, quality assurance of digestate, compost and briquettes would dispel fears or concerns related to utilisation of these products and this would boost sanitation system acceptability. Having examined certain socio-cultural aspects highlighted by the survey, appreciation of the enabling environments defined by existing regulatory requirements and relevant institutions was deemed necessary. Section 10.3 includes a review of the available regulations relevant for the sanitation systems proposed for **UCU**.

10.3 Institutional and Regulatory Requirements

Generally, existence of an enabling environment defined by institutional and regulatory requirements is a crucial component for sanitation system planning and implementation as already highlighted in previous Chapters. As such, key institutions deemed relevant with regards to the sanitation system alternatives were identified and these included; government ministries, NGO`s, local authorities, financial institutions(banks), regulatory bodies, contractors, local farmers and potential suppliers of substrates already summarised in Table 10-1. No further discussion regarding institutional requirements was carried out in this section since a summary of their respective roles and influence or power was included in Table 10-1.

Adherence to the relevant regulations, policies and standards for the sanitation systems was considered to ensure that compliance at various stages would be catered for and attained. Hence, early inclusion of relevant authorities during the planning phase would prevent failure or rejection of sanitation systems since necessary approval would be availed based on compliance. Thus, a review of the relevant national regulations, policies and standards for sanitation was carried out.

A recent comparative assessment of sanitation policies for Uganda and other East African countries indicated that despite the existence of related regulatory and institutional framework, the implementation process was flawed in many ways. The two key gaps were lack or inadequate financing for sanitation and lack of technical capacity, especially at the district level (Ekane et al. 2016). These gaps were further exposed by fact that Uganda had different policies for sanitation and hygiene. Moreover, the respective roles and responsibilities for the promotion and provision of these policies were generally widely spread in different ministries making it difficult to track progress.

Different government agencies, non-governmental organizations and private operators were involved in promotion and provision of sanitation and hygiene in Uganda. As such, the different entities had different strategies of intervention and responsibilities for sanitation and hygiene were not clearly defined. Therefore, overlapping of sanitation interventions and confusion among actors and key stakeholders resulted.

Such scenarios eventually brought about ineffective coordination of actors and key stakeholders, affecting their activities at different levels and these were major hiccups to translating sanitation and hygiene policies into practice. In spite of the grim findings of this comparative assessment, a general understanding of the heighted challenges was recognised and efforts were underway to clarify, redefine and reassign roles and responsibilities (Ekane et al. 2016).

Based on the highlighted issues pertinent to the regulatory and institutional framework for sanitation in Uganda, an assessment of relevant aspects for the proposed sanitation systems for **UCU** was justified. Furthermore, fulfillment of the regulatory requirements implied **UCU** could benefit from incentives in the form of fee or tax waivers and subsidies from the government or regulatory authorities. For instance, in case composting of organic waste was considered at **UCU** with reference to the **COMPAD** alternative**,** then in collaboration with **NEMA**, the University could benefit by registering the sanitation system as a Clean Development Mechanism(CDM) project (CDM 2009). Such **CDM** projects obtain certified emission reduction (**CER**), which could be a source of additional income to the University.

Furthermore, incentives in the form of tax waivers for sanitation system equipment purchase could be obtained with assistance from the Ministry of Energy Mineral Development **(MEMD) -** Renewable Energy Department. The incentives would be based on the Renewable Energy Policy of Uganda, which proposes to promote "waste to energy" projects, a theme that relates to the sanitation systems alternatives suggested for **UCU** (MEMD 2007, 2012). Considering that the proposed sanitation system alternatives consist of a combination of processes/technologies, some of which are common to all alternatives i.e. anaerobic digestion, a review of the relevant regulations, policies, standards and bylaws was carried out and a summary included in Table 10-3.

Table 10-3: Summary of Relevant Regulations, Standards, Policies and Ordinances

National Regulations	**Purpose**	**Responsible Authority/ Regulatory Body**
National Sanitation Policy for Uganda, 1997[a]	Gives a general approach to sanitation in Uganda by promoting and preserving the health of the community through improved sanitation	
National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, 1999[b]	Guidance on standards for discharge of effluent or wastewater in water or land	**NEMA** with additionally assistance from **NWSC**
Environmental Impact Assessment regulation S.I. No. 13/1998[b]	Guidance on carrying out environmental impact assessments for projects for which the proposed sanitation system alternatives are inclusive	**NEMA**
National Environment (Waste Management) Regulations, 1999[b]	Guidance on disposal of waste	**NEMA**
National Environment(Air Quality) Regulations-2016-draft	Guidance on emissions including from waste incinerators	**NEMA**
Renewable Energy Policy for Uganda 2007[c]	Guidance on increasing the use of modern renewable energy from 4% to 61% of the total energy consumption by the year 2017.	**MEMD**
Reference to other ordinances or bylaws		
Local Governments (Kampala City Council) (Solid Waste Management) Ordinance [d]	Guidance on methods of disposal of solid waste such as incineration, landfilling, including restrictions on landfilling of human excreta and objectionable waste solvents	**NEMA**
Clean development mechanism(CDM) Small-scale programme of activities design: document form (**CDM-SSC-PoA-DD),2009**[e] i.e. Uganda Municipal Waste Compost programme	Guidance on management of organic waste through composting thus, avoiding methane emissions. Also, guidance on composting projects as CDM projects and certified emission reduction (CER) is given.	**NEMA**

Relevant draft standards, codes of practice and relevant international regulation		
Draft Standards; Design and construction of domestic biogas plants	Although currently limited to domestic biogas plants, information on biogas quality improvement, biogas and digestate utilisation would be relevant for proposed sanitation system alternatives.	**UNBS**
National air quality standards and regulations, 2005 [h]	Avail necessary guidance to check air pollution from incinerators among other applications.	**NEMA**
EPA standard on sewage sludge application on land [f]	Guidance on quality of sewage sludge permissible for land application	
Directive **86/278/EEC** for sewage sludge application on land [g]	Guidance on quality of sewage sludge permissible for land application	

Sources: a- (GoU 1997) b- (NEMA 1995), c- (MEMD 2007), d- (KCCA 1997), e (CDM 2009), f (EPA 1994), g (EC 2001),h (Akello 2005)
UNBS; Uganda National Bureau of Standards

10.3.1 Discussion

In addition to reference to existing national regulations and policies, information from ordinances, programme documents, standards and pending drafts was also considered relevant for regulatory requirement review. The Kampala City Council Authority solid waste management ordinance for example illuminated restrictions pertaining the disposal of human excreta from septic sewage tanks, institutions etc. at landfills. These restrictions were not clearly stipulated in the National Environment Waste Management Regulations. Moreover, reference to the Uganda Municipal Waste Compost Programme documents gave guidance on composting of organic waste and highlighted the possibility of collaboration or consultation with **NEMA** regarding **CDM** projects among others. Despite the proposed utilisation of digestate and compost from sewage and faecal sludge, the absence of any national standards giving necessary guidance on land application of such inputs implied that reference to **EPA** 831-B-93-002 and Directive **86/278/EEC** could be considered. The mentioned standard and directive give guidance on the required quality of sewage sludge in case of application on land (Akello 2005).

Nationally, reference can be made to the conditioner/organic fertilizer quality from the National Water and Sewerage Corporation (**NWSC)** faecal sludge treatments plants at Lubigi and Bugolobi. Currently, the treated faecal and sewage sludge from these treatment plants is purchased by interested farmers and landscapers who use it as organic fertilizer and conditioner respectively. Although there are no national standards for such biosolids application on land, reference to the quality standards stipulated by **NWSC** while additionally incorporating the international standards mentioned could boost quality assurance of the digestate and compost from proposed sanitation system alternatives. In addition, information regarding biogas and digestate utilisation could be obtained from the draft standards for biogas design and construction of domestic biogas plants in Uganda.

Furthermore, the absence of a national incineration policy or regulation implies necessary guidance related to co-incineration of sewage sludge and medical waste is limited. Nevertheless, reference can be made to the draft national air quality standards and regulations developed by NEMA and released in 2005, which also include provisions for emissions from incinerators (Akello 2005). There is no doubt that a more specific regulation/standard relevant for incineration would be eventually required to effectively check pollution from incineration in case of future scale up and application of the technology. Moreover, the necessary man power and technical knowhow to ensure necessary compliance checks would be required.

As already mentioned, reference to and fulfillment of the existing regulatory requirements creates an enabling environment for future planning and implementation of any of the sanitation system alternatives. Nevertheless, more specific regulations, standards or policies would be necessary to validate compost and digestate quality for example, especially in case faecal and sewage sludge are co-composted with organic waste or anaerobically digested.

Moreover, inclusion of monitoring and enforcement measures within the various regulatory requirements would be a necessary boost since similar gaps have been cited in certain existing regulations. Inclusion of monitoring and evaluation measures would simplify compliance checks during system audits. Meanwhile, additional human and technical resources would be required to enable monitoring and enforcement of relevant regulations (SDC 2005; Akello 2007).

In conclusion, the assessment of the socio-cultural aspects of the sanitation system alternatives proposed for **UCU** implied that an understanding of relevant stakeholders was imperative to enable attainment of necessary information. As such, a stakeholder analysis was carried out to identify and categorise stakeholders. The outcome of the stakeholder analysis among others highlighted the significant role of **UCU**, leading to a survey of stakeholders from the University**.** The survey availed information on the overall stakeholder *perception* towards utilisation of sanitation system products. Furthermore, the *level of convenience* attached to system alternatives and the respective *system acceptability* was determined from the survey. Having obtained the key findings from the survey, a review of the available regulatory framework was carried to appreciate the enabling environment related to planning and implementation of the proposed sanitation system alternatives. The review of regulatory requirements showed that there are existing regulations, policies, standards and ordinances that could be referred to although more specific regulations with reference to biosolid application on land are additionally required.

The findings from the socio-cultural assessment for **UCU** also acts as a "tool box" from which guidance can be obtained for similar assessments for integrated sanitation systems for other urban area domains i.e housing estates, other institutions, peri-urban areas, towns and cities. Primarily, it is crucial that stakeholders are identified and that their roles, interests, control/power as well as their interrelations are determined. This indicates that a stakeholder analysis is a crucial component for socio-cultural assessment. Moreover, during the stakeholder analysis stage, it is also important to identify project "champions" although they could also have been identified at the initiation phase of the integrated sanitation system project. While there are bound to be variable stakeholder groups depending on the entities involved or implementing the integrated sanitation system approach, certain stakeholder groups may be common to entities considered. Stakeholder groups such as local authorities, regulatory bodies, non-governmental organisations (NGO`s), funding organisations and contractors among others may be common to all entities considering integrated sanitation system implementation.

Not worthy is that the level of power or control that these stakeholder groups could have may vary in the different urban domains considered. For instance, regulatory bodies or local authorities could act as champions of projects and also primary stakeholders in case an integrated sanitation system is considered for cities or towns. As such, the mentioned stakeholder groups would have high influence. While the level of power or control by similar stakeholder groups may be much less in case the integrated sanitation system approach is considered for housing estates developed by private developers.

Moreover, the level of skill required within a particular integrated sanitation system and the available human resource may also influence the control that contractors have with respect to planning and implementation of system. For instance, private contractors may be mandated to operate and manage integrated sanitation systems at housing estates as well as at city and town projects. As such, the power the contractors would have would be higher in comparison to cases where operation and maintenance was carried out by the very entity who installed the integrated sanitation system. Besides, understanding of the sanitation system`s main goal, especially in relation with by-product utilisation could also influence the control or power wielded by benefactors for instance. High demand for electricity by a private entity could influence the input from regulatory bodies on the project.

The stakeholder analysis process is also an iterative process, which can be applied at various stages of planning and possibly implementation of the integrated sanitation systems. Intrinsically, the stakeholder analysis process evolves and incorporation of relevant changes should be considered through the project life. For instance, if at a later stage of the project, demand for briquettes increases, then incorporation of briquette customers and possibly necessary regulatory bodies would be crucial. This also allows for further organisation and structuring of various actors, which in turn boosts coordination. Moreover, all through the analysis process, clear delineation of stakeholder roles as primary or secondary can be achieved and through identification of interests, the stakeholder analysis plays an anticipatory role for integrated sanitation system implementation. Noteworthy is that throughout the stakeholder analysis process, sensitisation and raising awareness of the integrated sanitation system approach is essential since various actors are involved. Besides, often the case the various actors may not necessarily be sanitation, energy or engineering experts thus, continually informing them of the sanitation system objectives and goals is salient.

The socio-cultural assessment, which could include investigating the acceptability of the integrated sanitation systems is often influenced by culture. As such, perception and attitude towards the sanitation systems could inherently influence system acceptability. With reference to the integrated sanitation system approach, which considers combined management of organic waste streams, system acceptability can be hinged to reduced public health and environmental impacts as well as expectations from by-product utilisation. Reduced exposure of system users to public health risks could become a key influential factor to accepting the integrated sanitation systems. Moreover, the same factor can play an influential role with regards to by-product utilisation. The fact that the integrated sanitation system considers sewage and faecal sludge, organic waste and wastewater effluent as waste streams to be managed further increases concerns related to public health risks. This could in turn influence the overall system acceptability.

Experiences from the socio-cultural assessment carried out for **UCU** highlight the importance of sensitisation and raising awareness about the sanitation systems as well as the utilisation of by-products. Irrespective of the entity considering the implementation of integrated sanitation systems i.e housing estates, institutions, towns and cities, raising awareness and sensitising the various actors is crucial. Sensitisation and raising awareness have been identified as tools that influence behaviour change (Peal et al. 2010; Sawyer et al. 1998; Lüthi et al. 2011a). As such, the willingness to utililise by-products such as biogas for cooking and digestate as organic fertilizer can be increased amongst various actors through sensitisation and raising awareness. Besides, behaviour change with reference to how the organic waste streams are regarded could also improve due to sensitisation. This could lead to consideration of organic waste as a "resource" rather than a "nuisance", motivating actions such sorting and separation of waste among others. In addition, to sensitisation and raising awareness, ensuring the quality of the by-products could also boost acceptability of the sanitation systems. For example, if the quality of digestate can be checked against guidelines used either regionally or locally, then acceptability of the systems can be enhanced.

Reference to regional, national and local regulatory framework is crucial for system acceptability since failure to comply with existing regulations could lead to rejection of the systems. In cases where there is absence of necessary national or local regulations as is the case with regards to biosolid application on land, then reference to regional regulations such as those stipulated by the European Union among others can be considered. Besides, reference to and collaboration with other actors already involved in production of soil conditioner or fertilizer from similar waste streams can be considered. In Uganda, National Water and Sewerage Corporation (NWSC) is mainly involved in producing and selling soil conditioner produced from sewage and faecal sludge treatment. Collaboration with such entities could also contribute to the development of national or local guidelines for checking quality of such biosolids within the country. Moreover, by developing an institutional framework, additional collaboration opportunities could exist amongst various actors and NGO`s or research institutions. In case an integrated sanitation system is developed for a housing estate or institution, collaboration with NGO`s such as **Water for the People**, **GIZ** or government bodies such as **NWSC** who are involved in projects related to resource recovery from similar organic waste streams, could boost quality assurance of by-products from the integrated sanitation systems.

Generally, it can be noted that inter-linkages between the four aspects initially considered for holistic feasibility assessments exist. Public health concerns associated with management of the organic waste streams and utilisation of system by-products influence sanitation system acceptability. While the reduction of environmental impacts from the management of organic waste streams represented as carbon offsets also influences the economic feasibility as well as acceptability of the integrated sanitation systems. Moreover, technical aspects of the integrated sanitation systems defined by system complexity or skill requirement could in turn influence acceptability, especially in cases where the responsible entities are expected to operate and manage the system.

Having carried out the technical, environmental, economic and socio-cultural feasibility assessments of the sanitation system alternatives proposed for **UCU**, the inter-linkages initially foreseen between the four aspects can be traced. Therefore, to further have a complete view of all aspects while promoting transparency and including holistic considerations reflected by the interdependency of aspects, sustainability assessment of the integrated system alternatives was carried out. As noted in the conceptual framework, reference to the Helmholtz integrative concept for sustainable development additionally informs the sustainability assessment of the integrated sanitation system alternatives discussed in Chapter 11 of this dissertation.

11 Sustainability Assessment of Sanitation System Alternatives

Chapter ***11*** *discusses the sustainability assessment of the sanitation system alternatives proposed for* ***UCU*** *using multi-criteria decision analysis. A stakeholder participatory approach is adopted in the multi-criteria analysis process. The Chapter concludes with a sensitivity analysis and a discussion of general aspects to consider in case sustainability assessment of integrated sanitation systems for other entities is taken into account.*

11.1 Application of MCDA for Sustainability Assessment of Sanitation System Alternatives

The sustainability assessment of the sanitation system alternatives proposed for **UCU** was carried out using multi criteria decision analysis **(MCDA**) as described in Chapter 5 of this of this dissertation. The sustainability assessment is informed by the findings from the feasibility assessments and reference to the Helmholtz integrative concept of sustainability development. The **MCDA** was carried with reference to the procedure suggested by Yatsalo et al. (2015) as shown in Figure 11-1.

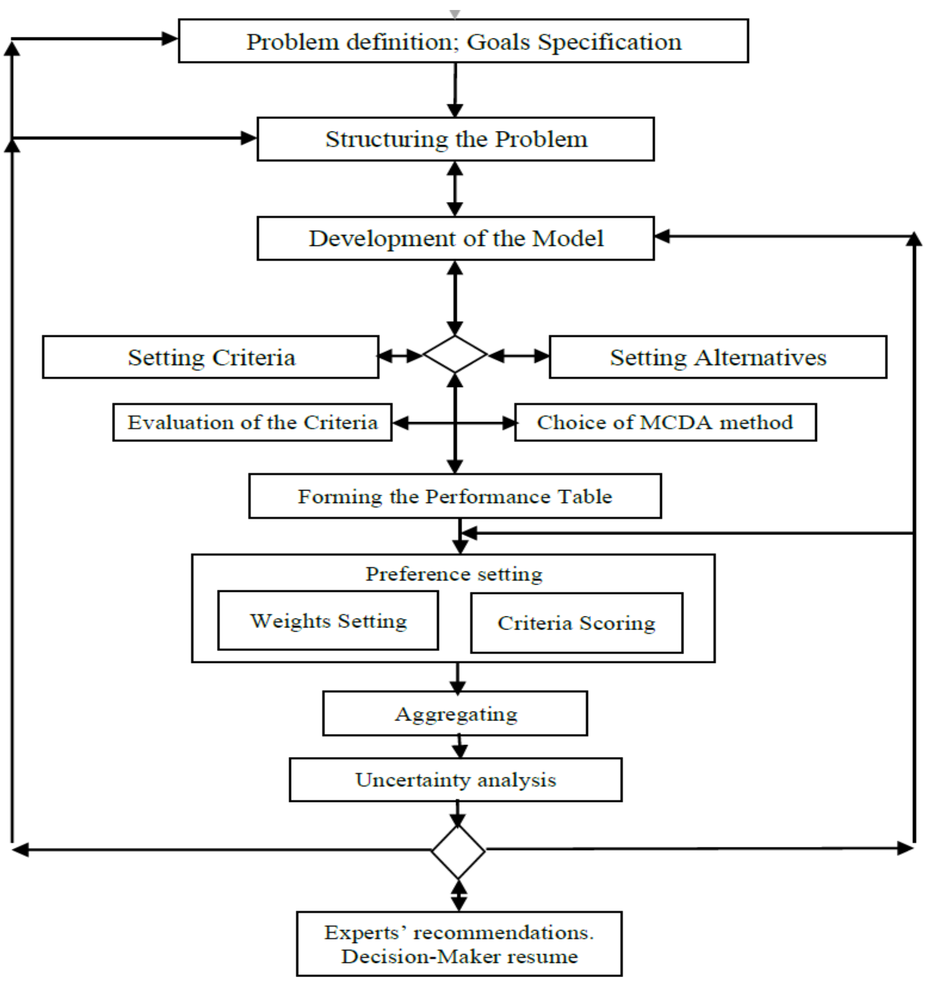

Figure 11-1: MCDA procedure
Source: (Yatsalo et al. 2015)

11.1.1 Problem Definition

With reference to **UCU**, the problem definition was already described in the previous chapters and is summarised here as; the requirement of sustainable sanitation within the University. In addition, the University is interested in reducing her dependence on firewood utilisation for cooking by using clean energy sources such as biogas. As such, **UCU** proposes the management of organic materials such as sewage sludge from the University **WWTP** as a means to provide the much needed biogas.

11.1.2 Problem Structuring

This stage takes into consideration the values as well as the fundamental and means objectives of the sanitation system alternatives being assessed. Moreover, the key issues related to sanitation in addition to the goals and constraints influenced by the external environment are considered. The necessary guidance for the decision process is developed at this stage. Furthermore, identification of alternatives and relevant stakeholders while reflecting on possible uncertainties is also accomplished in this stage thus, enabling the structuring of the problem (Olson 1996; Belton and Stewart 2002).

Given that the values of decision makers and relevant stakeholders are made explicit based on objectives defined, it is imperative that a proper understanding of the objectives is achieved. In understanding the objectives, the definition of the objective types i.e. *fundamental* and *means* objectives should be taken into account. Keeney (1992) describes fundamental objectives as the basis for which any interest in the decision is considered. These *objectives* qualitatively state all that is of concern in the decision context thus, these objectives provide guidance for action and are the foundation for any quantitative modeling or analysis that may proceed. The *means objectives* are of interest because of their implications for the degree to which the *fundamental objectives* can be achieved (Keeney 1992).

With reference to **UCU**, despite currently managing the various waste streams generated from the University in different ways, **UCU** still experiences a major challenge in the final disposal of sewage sludge from the lagoons at the **WWTP**. Therefore, improvement of the existing sanitation system was proposed with the two fold objective (*means objective*) of achieving improved sanitation and ensuring resource recovery in the form of biogas and nutrients. Six sanitation system alternatives were designed and these include; **Status Quo**, **COMPAD**, **COMPAD LF, INCAD, INTEG 1**and **INTEG 2**. Hence, with reference to the system alternatives designed, the fundamental objective of the **MCDA** was assessment of sustainability of these systems alternatives proposed for **UCU**.

Having clearly identified the objectives and alternatives to be assessed, appreciation of the relevant decision makers and stakeholders was crucial. With reference to the sanitation system alternatives proposed, relevant stakeholders who were considered to have influence were identified, categorised and an analysis carried out to determine their interrelations.

An understanding of the relevant stakeholders and decision makers was attained and this informed other stages of the **MCDA**. With reference to this research, the decision makers consisted of stakeholders from **UCU i.e.** lecturers, technical staff and students whose opinion was considered to influence the final decision made by the University management. Other stakeholders included relevant government authorities/regulatory bodies, NGO`s, and experts/professionals in the fields of sanitation, biogas, and environment in Uganda.

11.1.3 Model Development

The model development stage includes specifying alternatives, defining criteria and eliciting values(Belton and Stewart 2002; Yatsalo et al. 2015). An understanding of whether the application of an "*alternatives-based approach*"" or "*criterion based approach"* is critical for guiding model development. With reference to the "*alternatives-based approach*", alternatives are presented for consideration and then the criteria are selected for their analysis. While the "*criterion based approach*" considers criteria for reaching the goal(s), then alternatives are formed based on suitable criteria (Yatsalo et al. 2015). For the **UCU** scenario an "alternatives based approach" was considered by taking in to account the defined six sanitation system alternatives, then criteria were selected for the assessment of the alternatives. Given that sustainability of sanitation system portrays a multi-dimensional stance, a set of sustainability criteria were considered for the assessment of the system alternatives.

11.2 Sustainability Criteria Requirements

Sustainability criteria groups were considered with reference to the four aspects i.e; environmental and natural resources, economic, socio-cultural and technical. Furthermore, reference to the Helmholtz integrative concept in addition to relevant literature review of sustainability assessments for sanitation systems gave an overall picture of primary criteria considered. Moreover, reference to **UCU** context in addition to input from stakeholders and experts enabled further screening and selection of final criteria set. Also, reference to requirements for setting criteria informed the process of criteria screening. Thus, criteria requirements, which included checking for completeness or relevance, ensuring mutual independence, avoidance of redundancy and double counting were taken into account (Belton and Stewart 2002; Van Buuren 2010).

11.2.1.1 Relevance and Completeness

In considering this requirement, the decision makers should be able to link the concept being investigated to their goals with the criteria set and this should enable them to specify preferences. Furthermore, the criteria set should enable evaluation of all relevant aspects of the performance of system alternatives under study. Thus, the ability to understand the criteria is equally important since it enables preference evaluation while additionally incorporating completeness. Thus, all important aspects of the problem should be captured (Van Buuren 2010; Belton and Stewart 2002).

11.2.1.2 Avoidance of Double Counting

Double counting occurs when the effect of a certain factor on an alternative`s performance is counted more than once and this should be avoided (Belton and Stewart 2002). Keeney (1992) further suggests that double counting can be avoided by differentiating between the *means* and *fundamental* objectives. In addition, only the *fundamental objectives* should be incorporated in case a value tree is used for evaluating alternatives. This would limit any possibility of confusion.

11.2.1.3 Redundancy

This requirement checks whether there is more than one criterion measuring the same factor. In eliminating redundant criteria, a more concise criteria set should be generated and this mitigates the huge effort required for alternatives assessment, particularly if the number of alternatives is large. As such, at the initial stage of developing a criteria set, the less important criteria can be identified by making an importance ranking where only the most important criteria are included in the set for assessment (Belton and Stewart 2002; Van Buuren 2010).

11.2.1.4 Mutual Independence of Preferences

Ideally it should be possible to independently assess the different criteria selected. The possibility to assign a performance score to a criterion without checking for the performance score of other criteria for an alternative reflects mutual independence. If preferences with respect to a single criterion, or trade-offs between two criteria depend on the level of another, then mutual dependence exists. A lack of mutual independence could distort the comparison of alternatives, especially in case the overall preference value or utility is required (Belton and Stewart 2002; Van Buuren 2010). Other requirements such as ensuring simplicity in representation of the complex problem were also taken into consideration during the determination of the criteria set used for assessment of the sanitation system alternatives.

11.2.2 Generation of a Sustainability Criteria and Indicator Set for UCU

Considering that numerous sustainability criteria sets for assessment of sanitation systems have already been generated, it was crucial that the criteria set generated represented the **UCU** scenario. As such, a review of literature on existing sustainability criteria sets for assessment of sanitation systems was carried out. Once a preliminary set of criteria and indicators were developed, reference was made to the Helmholtz integrative concept sustainability goals and rules/principles relevant for sanitation systems proposed. This allowed for further identification of indicators that defined the preliminary criteria set. Concurrently, reference to the local context i.e. **UCU** and the neighbouring environment, taking in to consideration the proposed sanitation system value chains was carried out.

The generated criteria and indicator set was then reviewed by stakeholders and experts who gave their input and necessary modifications were incorporated. This procedure allowed for final refining of the criteria and indicator set. The input from the stakeholders and experts was obtained through interviews and consultation meetings. Figure 11-2 shows how the sustainability criteria and indicator set for sustainability assessment of sanitation system alternatives proposed for **UCU** was generated.

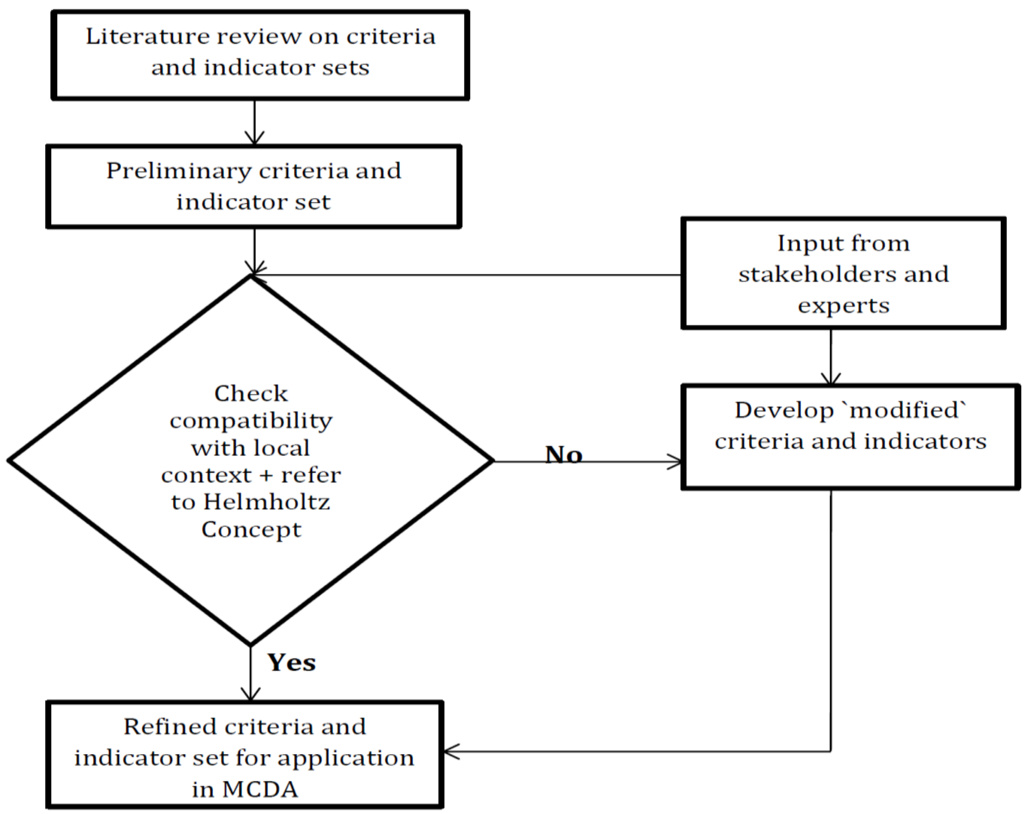

Figure 11-2: Generation of the sustainability criteria and indicator Set
Source: Author

The *fundamental objective* of the **MCDA** i.e. assessment of sustainability of the sanitation system alternatives was broadly represented under the four aspects i.e. environmental and natural resources, economic, socio-cultural and technical. Thereafter, more specific criteria for the respective aspects were generated and further defined as performance indicators to limit ambiguity as much as possible (Belton and Stewart 2002). As shown in Figure 11-2, a combination of activities/steps enabled the screening and elimination of criteria and indicators deemed irrelevant for the sustainability assessment of system alternatives proposed for **UCU**.

11.2.3 Sustainability Principles for Sanitation System Assessment:

First of all, it is crucial to determine which rules/principles of sustainability are relevant for the technology or in this case the sanitation systems assessment. This always has to be done regarding the technologies and the context under consideration (Grunwald and Rösch 2011; Grunwald 2012; Kopfmüller et al. 2001). With reference to the sanitation systems proposed for **UCU**, the following rules apply;

11.2.3.1 Protection of Human Health

The dangers and intolerable risks on human health due to anthropogenically caused environmental impacts have to be avoided. Impacts from various phases of the proposed sanitation system, which may include the construction, operation and maintenance might negatively affect human health both in the short or long term (Grunwald and Rösch 2011; Grunwald 2012). Therefore, the health risks due to any of the activities from the sanitation systems proposed for **UCU** have to be taken into considerations. Examples could include risk of pathogens exposure due to use of system products such as digestate and compost or air pollution due to incineration of waste.

11.2.3.2 Securing the Satisfaction of Basic Needs

Here, minimum basic services (accommodation, nutrition, clothing, health) and the protection against central risks of life (illness, disability) have to be secured for all members of society (Grunwald 2012; Kopfmüller et al. 2001). The proposed sanitation systems should play outstanding roles in securing the satisfaction of basic human needs through for instance availing the necessary energy demands and satisfying other needs such as organic waste and sewage management.

11.2.3.3 Sustainable Use of Renewable Resources

The general concept within this principle is that the usage rate of renewable resources must neither exceed their replenishment rate nor endanger the efficiency and reliability of the respective ecosystem (Kopfmüller et al. 2001; Grunwald 2012). Thus, in the context of this research, the proposed sanitation system alternatives are designed with an additional objective of generating clean energy sources for cooking i.e. biogas. As such, the dependence of **UCU** on firewood for cooking purposes would be reduced and this could contribute to reducing deforestation in the country.

11.2.3.4 Sustainable Use of Non-Renewable Resources

The reserves of proven non-renewable resources such as diesel or other materials required for running the proposed sanitation system have to be preserved over time. The mere fact that cogeneration of electricity and heat could be considered for the proposed sanitation systems implies that the use of non-renewable resources such as diesel used as backup fuel for electricity generation at the University could be reduced. Moreover, the potential substitution of mineral fertilizer with organic fertilizer that would be generated from the sanitation systems further contributes to sustainable use of non-renewable resources.

11.2.3.5 Sustainable Use of the Environment as a Sink

In an ideal case, the release of substances from various technologies must not exceed the absorption capacity of the environmental media and ecosystems. The variable activities related to the life cycle of a product or system may result in emissions. Some of these activities include; extraction of natural resources, processing of materials, energy consumption, transportation, production processes, use of various technologies and waste disposal processes. These emissions which are then released into the environmental media such as water, air, and soil cause serious local or regional problems, especially concerning the quality of air, ecosystems, biodiversity, freshwater and the climate (Grunwald 2012; Grunwald and Rösch 2011).

With reference to the sanitation system alternatives proposed for **UCU**, the main goal of management of the organic waste streams should generally contribute to the reduction of emissions to the environment. As such, utilisation of biogas from anaerobic digestion of organic waste streams would result in avoided greenhouse gas (GHG) emissions. Moreover, complete treatment of sewage sludge instead of improper disposal when partially treated would reduce eutrophication impacts on the environment.

11.2.3.6 Participation in Societal Decision-Making Processes

All members of the society must have the opportunity to participate in societally relevant decision-making processes. With regards to technology, this principle has a procedural feature. Substantially, participation affects the design of technologies, which might be used with various participants having variable input and this input may be difficult to incorporate. In this instance, the principle calls for exploiting the potentials of participation as far as possible. Procedurally, the principle aims at the conservation, extension, and improvement of democratic forms of decision-making and conflict resolution, especially regarding those decisions which are of key importance for the future development and shaping of the society (Grunwald 2012; Grunwald and Rösch 2011). With reference to the sanitation systems proposed for **UCU**, the procedural aspect is adopted since participation is considered a key component in sanitation interventions.

11.2.3.7 Avoiding Technical Risks with Potential Catastrophic Impacts

Technical risks with potentially catastrophic impacts on humanity and the environment must be avoided. Formulation of this principle was deemed necessary since the risk component may be insufficiently incorporated in other sustainability principles. As such, setting limits that help in defining the normal operation of technologies would be imperative in checking risks. Such limits would for example, stipulate the maximum pollutant levels in environmental media from a particular technology and guide on how to weigh the risks. However, this principle generally orients itself on “trouble-free, normal operation“, and leaves the possibility of breakdowns out of consideration to a great extent (Grunwald 2012). With reference to the sanitation systems proposed for **UCU**, failure in operation of the anaerobic digester for example could result in emission of greenhouse gases to the environment.

Moreover, in worst case scenarios, fires or explosions within the digester unit cannot be ruled out when biogas leakages are accidentally ignited. Such occurrences due to system failure could have catastrophic impacts to the system operators as well as the University community.

11.2.3.8 Appropriate Discounting

Discounting shall neither discriminate against today`s nor future generations. The discounting procedures are used to make effects in the form of economically relevant quantities which occur at different times comparable and assessable for current decision-making processes. As such, the cost and benefit items, which result from investments and other activities in the course of the given period are discounted to their current or cash value (Grunwald 2012; Grunwald and Rösch 2011). In assessing the economic feasibility of the sanitation systems proposed for **UCU,** discounting was carried out. Moreover, sensitivity of different discount rates was additionally incorporated in the assessment to reflect any possible changes that may occur at different time.

Worthy of mention is that the sustainability principles discussed do not have a prescriptive character for technology design but provide the necessary orientation for which improvement in the technology design can be achieved (Grunwald 2012). Table 11-1 gives a summary of the substantial principles of sustainability discussed and the corresponding indicators identified.

Table 11-1: Reference to the Helmholtz Concept of Sustainable Development: Selection of Relevant Principles and Indicators

Substantial principles of sustainability	**Indicators**
Protection of Human health	• Human toxicity potential
Securing satisfaction of basic needs	• Adaptation to new conditions and requirements • Utilise locally available material and skilled labor for construction of sanitation system • Utilise locally available materials and labour for operation and maintenance of sanitation system
Sustainable use of renewable resources	• Energy recovery • Nutrient recovery • Water reuse
Sustainable use of non-renewable resources	• Land requirement
Sustainable use of environment as a sink	• Global warming potential • Eutrophication potential
Participation in societal decision making	• Perception • Convenience
Avoiding technical risks with potentially catastrophic impacts	• Sensitivity of sanitation system to shock loads • Risk of sanitation system to failure
Appropriate discounting	• Life cycle costs • Benefit cost ratio

Source: Author

11.2.4 Description of Criteria and Indicator Set

Having described the sustainability aspects in the previous Chapters of this dissertation, this section focuses on description of the criteria and indicator set considered with reference to sanitation system alternatives proposed for **UCU.**

11.2.4.1 Environmental and Natural Resources Aspect

Within this aspect, three criteria were considered. These included; resource use, environmental burden/impact and resource recovery. Further definition of the respective criteria using indicators was carried out as explained.

Resource use**;** takes into account the various inputs required for the sanitation system which cannot be ignored (Andersson et al. 2016a). Resource utilisation for sanitation systems can be divided into the various stages of the system i.e. construction, operation and maintenance as well as demolition. However, for the **UCU** system alternatives only *land requirement* was considered under the resource utilisation criteria. *Land requirement* is an important determining factor, especially in cases of land scarcity since enormous costs would be incurred to purchase required land.

Such a scenario can be related to **UCU** which is located in Mukono Municipality, where requirement for additional land would imply incurring additional costs. Other inputs for construction and operation stages of the sanitation system which would otherwise be considered as utilised resources were incorporated in the *life cycle costs* indicator defined under the economic aspect. Thus, to avoid double counting of criteria, further inclusion of other indicators within this criterion was limited.

***Environmental burden*;** basically considered the impact on environment caused by the sanitation system. With respect to the system alternatives for **UCU,** only three impact categories i.e. *global warming potential*, *eutrophication potential* and *human toxicity potential* were considered to define this criterion. The *global warming potential* represented the impact to environment due to greenhouse gas (**GHG**) emissions associated with energy input or material utilisation. Furthermore, **GHG** emissions from various organic waste treatment or handling processes for respective system alternatives were included. The *eutrophication potential* examined the enrichment of nutrients in aquatic or terrestrial environments, which could be expected from disposal of sanitation system products such as digestate, sewage sludge and compost. Finally, the *human toxicity potential* estimated the negative impact of system processes on human beings. Potential toxicity based on chemical composition of sanitation system products, their physical properties, point source of emissions were characterised. The characterisation was carried out according to the potential release of emissions to the environment using Gabi 6 **LCA** software (refer to Chapter 8). The *human toxicity potential* was chosen as an indicator because it was considered to be partly representative of the health aspect associated with the proposed sanitation systems(Gabi 2011; UNEP, SETAC 2005).

Noteworthy was that for all impact categories selected, only the operation and maintenance stage of the proposed sanitation systems was taken in to consideration. This decision was based on findings from numerous LCA`s, which suggest that environmental impacts from replacement of equipment and construction of facilities are much lower in comparison to impacts from operational stage (Emmerson et al. 1995; Pillay 2006; Remy 2010).

Resource recovery criterion*;** highlights the fact that sanitation systems should not be limited to handling, treatment and disposal of waste streams, but should additionally consider resource recovery. Thus, a circular economy trend is depicted where resource recovery in the form of nutrients, energy and water can be achieved from sanitation systems (Lennartsson 2009; Andersson et al. 2016a). In the assessment of the system alternatives proposed for **UCU,** *energy,** *nutrient and water recovery* indicators were considered. *Energy recovery* from the system alternatives was considered mainly from biogas generated from the anaerobic digestion process in addition to the potential utilisation of briquettes made from digestate. The *Nutrient recovery* indicator took into account the *nitrogen (N) potassium (K)* and *phosphorus (P)* nutrients recovered during proposed utilisation of compost and digestate as organic fertilizer (Lennartsson 2009).

The *Water recovery indicator* mainly reflected the proposed utilisation of effluent from the University **WWTP** as process water for the anaerobic digestion process. The assumption here was that by reusing effluent as process water, the requirement of fresh water for anaerobic digestion in the respective system alternatives would be reduced as described in Chapter 7.

11.2.4.2 Economic Aspect

The attractiveness of any investment is often hinged on how economically viable it is. As such, the economic aspect was defined by the *economic desirability criterion*.

***Economic desirability criterion*;** highlights the fact that costs always play an important role in system choice. Although often indicated as '*economic*', some related assessments focus on the costs and benefits of sanitation system alternatives, i.e. the financial impact rather than the impact on the economy was taken into consideration(van Buuren 2010). The *economic desirability* criterion was defined by *life cycle costs* and the *benefit cost ratio* of the respective system alternatives. The *life cycle costs* considered annual costs, including capital and operational costs for the system alternatives (Lennartsson 2009; Van Buuren 2010). While the *benefit cost ratio* as the name suggests included the ratio of the computed revenue accrued from potential resource recovery to the total annual operation and maintenance costs. The *benefit cost ratio* was meant to further reflect economic attractiveness of respective system alternatives.

11.2.4.3 Technical Aspect

The key parameters that define technical aspects or functionality of a sanitation system often include; robustness, flexibility, adaptability and durability among others (refer to Chapter 7). For the **UCU** scenario robustness, system complexity and flexibility were considered.

Robustness as an attribute of a technology could imply sturdiness, durability and resilience, which can be reflected by specific parameter such as simplicity of the process, absence of equipment that could breakdown easily (Van Buuren 2010). Specific to the **UCU** scenario**, robustness** was defined by the *sensitivity of sanitation system to shock loads* and *risk of a sanitation system to failure* indicators. *Sensitivity of a system to shock loads* examined how resilient the system was considered to be. Hence, effects on system performance due to absence or fluctuation of electricity, organic waste as inputs, variation in operation parameters such as temperature, pH and irregular maintenance was taken into account. While the *risk of a system to failure* examined system malfunction caused by inadequate management or treatment of the organic waste. Malfunction due to variation of system operation parameters such as temperature, pH and impacts due climatic conditions were also considered.

***Complexity of Sanitation Systems*;** is often reflected by the level of skill required for construction, operation and maintenance in addition to material requirements for respective stages of the system (Lennartsson 2009). With reference to **UCU,** complexity of sanitation systems was defined by two indicators i.e.**;** *possibility to utilise locally available material and labour for construction as well as operation and maintenance of sanitation systems.*

In this context, “local” implied within Uganda thus, material and labour available within the country was considered to reflect low level of system complexity, which would be preferred. With reference to the design considerations for system alternatives, ability to construct, operate and maintain the systems with material and locally available skilled labor would be advantageous. Avoidance of hiring external labour and purchase of imported material would make system alternatives attractive. Also, availability of labor for all stages of the sanitation system would imply long term sustainability.

***Flexibility criterion*;** generally refers to the efforts or cost needed in case of modification or upgrading of infrastructure or sanitation system when new conditions occur or requirements are set (Van Buuren 2010; Andersson et al. 2016a). For **UCU** system alternatives**,** *flexibility* was defined by *the adaptability of the sanitation system to new conditions and requirements.* Hence, the ease with which the sanitation systems were adaptable to variations in organic waste composition and quantities, climatic conditions and system upgrade among others were considered.

11.2.4.4 Socio-Cultural Aspects

In relation to sanitation, the socio-cultural aspects focus on securing people’s needs in an equitable way while incorporating human morality, relationships, and institutions (Vleuten-Balkema 2003). Sanitation system acceptability which is often influenced by culture was the main criterion considered under the socio-cultural aspect.

***Acceptability*;** of a sanitation system by relevant stakeholders and specifically users is crucial for its sustainability. As already highlighted in previous Chapters of this dissertation, ignoring user opinion may result in rejection or abandonment of sanitation systems (Andersson et al. 2016a; Kvanström et al. 2008). Influenced by culture, acceptability of the system alternatives proposed for **UCU** was defined by *perception* towards the system and the *level of convenience* attached to the system**.** *Perception* reflected the emotional response towards the sanitation system due to handling/management organic waste and utilisation of products i.e. organic fertilizer, solid fuels and biogas. Level of *convenience* attached examined the level of comfort users would attach to specific sanitation system alternatives. *Convenience* could be influenced by impacts such as noise, odor, alteration of aesthetics and safety concerns from transporting, handling or management of organic waste as highlighted in Chapter 10.

During criteria screening, it was identified that further inclusion of regulatory and institutional framework related criteria within the socio-cultural aspects would not enable specific assessment of system alternatives. The mere fact that a combined organic waste management approach was considered for the sanitation system alternatives proposed implied that similar regulatory and institutional support would be required. As such, any criteria and indicators related to regulatory and institutional requirements would be considered redundant. Therefore, Figure 11-3 gives a summary of the fundamental objective of this **MCDA** defined by key aspects, criteria and indicators represented in a value tree.

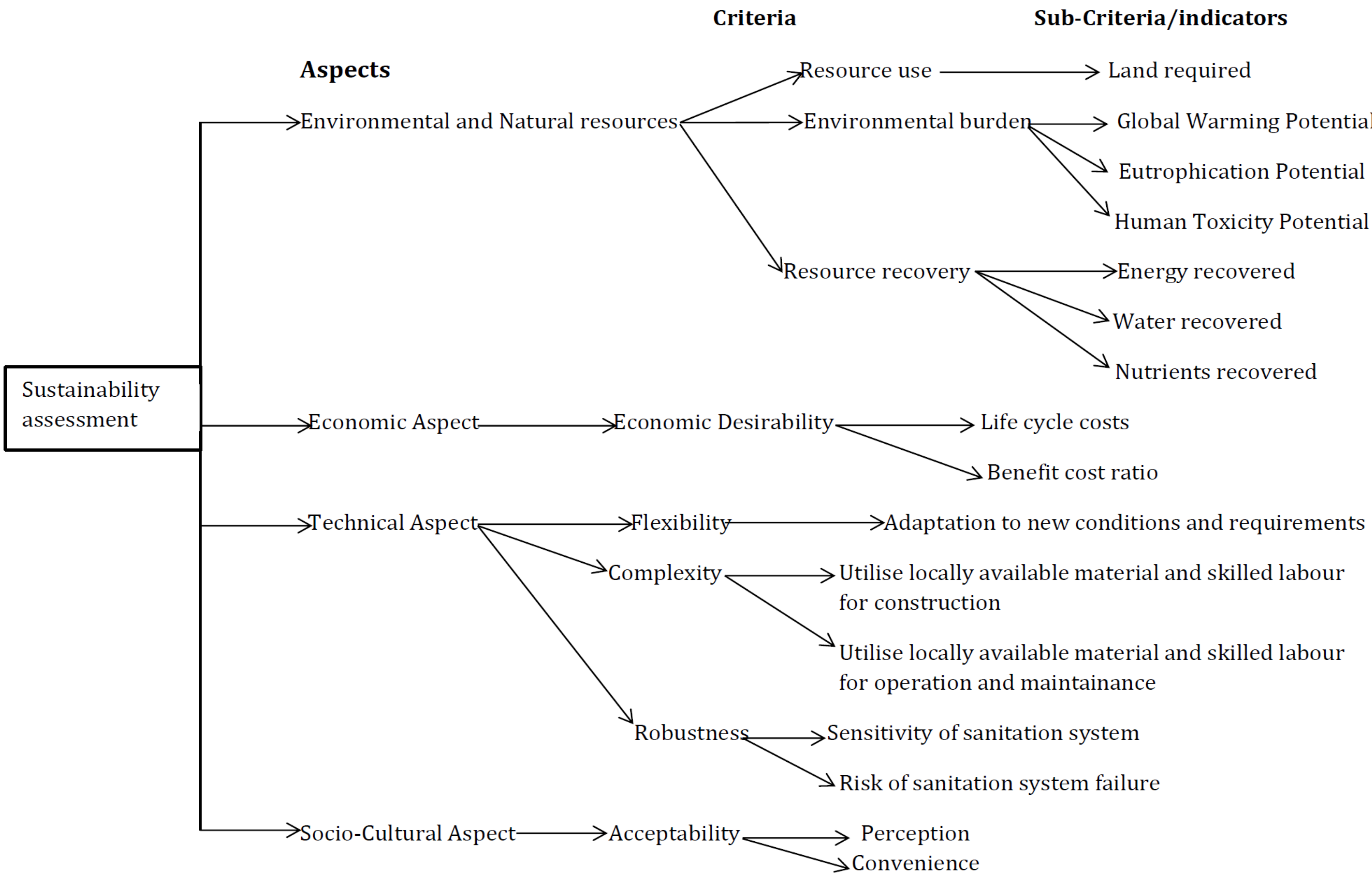

Figure 11-3: Value tree showing aspects, criteria and indicators
Source: Author

From the value tree represented in Figure 11-3, the indicators are considered to be children within a family. In cases where more than one indicator exists for example within the resource recovery criterion, then all the indicators are considered to be siblings within a family. The criteria are considered to be parents while the aspects are the grandparents (Belton and Stewart 2002).

11.3 Stakeholder Involvement in MCDA Process

Stakeholder involvement in sanitation system planning, selection and eventual implementation is extremely important for system sustainability as already highlighted. Stakeholder identification and definition of respective roles was already carried and discussed in previous Chapter. This section focuses on the involvement of stakeholder groups and experts in the **MCDA** process. Through involvement of stakeholders at this stage, the **MCDA** was considered to promote transparency in decision making. Lahdelma et al. (2000) further suggest specific stakeholder participation in the environmental multi-criteria decision process and summarise the respective stages of involvement as shown in Table 11-2.

Table 11-2: Summary of Stakeholder Participation in Environmental MCDA process

Stakeholders	Define alternatives and criteria	Make measurements	Choose decision aid	Provide preference information	Form draft solutions	Make final decision
Decision makers	X		X	X		X
Interest groups	X			X		
Experts	X	X				
Planners and Analysts	X	X	X		X	

Source: (Lahdelma et al. 2000)

In terms of the **MCDA** for **UCU**, definition of alternatives and criteria was enabled with input from various stakeholders. The Stakeholders typically include the decision makers, various interest groups affected by the decision, experts in the appropriate fields, as well as planners and, or analysts responsible for the necessary preparations and managing the process (Lahdelma et al. 2000). With reference to **UCU,** stakeholders from **UCU,** interest groups, experts and the researcher participated in the **MCDA.**

Stakeholders from UCU included; Lecturers from the *Department of Engineering & Environment,* specifically Lecturers in the fields of water and Sanitation, and other Lecturers from other departments i.e. sociology, business and gender were also consulted. Technical and engineering staff from the *Directorate of Facilities and Capital Projects at* **UCU** were also included within this category. Moreover, input from students at **UCU** was also obtained through the survey discussed in Chapter 10.

Input from this stakeholder category informed modeling of sanitation system alternatives as well as criteria and indicator selection. Moreover, the stakeholders were also involved in assigning score and weight values for criteria and indicators for respective sanitation system alternatives.

Experts mainly included; professionals in the fields of sanitation, biogas, environment and renewable energy within Uganda. Input informing modeling of sanitation system alternatives and elicitation of score and weight values for the selected criteria and indicator was obtained from this stakeholder group.

Interest groups; under this category, information was obtained from Mukono Municipality officials and this enabled modeling of system alternatives and criteria selection**.** Lastly, based on in-depth literature review and feasibility assessments discussed in Chapters 7 to 10 of this dissertation, modeling of alternatives and criteria identification was also carried out by the researcher.

Based on the input from various experts and literature review, relevant measurements and assessments were carried out and this informed the **MCDA** process as well. While an informed choice of the decision aid used for modeling during the **MCDA** was made by the researcher. Elicitation of **MCDA** input from experts was carried out to obtain alternative opinion with the view of checking any bias or anomalies. Drafting of solutions based on evaluation of the sanitation system alternatives was accomplished by the researcher and compiled in this dissertation with the aim of guiding the decision making process that would be completed by **UCU**.

As noted in the stakeholder analysis discussed in Chapter 10, **UCU** plays a significant role as potential system users, funder/implementers etc. thus, are considered the main decision maker. Despite the fact that the final decision on choice of the sanitation system would be made by **UCU`s** top management, input from the students, teaching and non-teaching staff was considered to inform the final decision. As such, the input from students, teaching and non-teaching staff from **UCU** was considered to inform the final decision making process. Therefore, Table 11-3 summarises stakeholder involvement in the **MCDA** for **UCU.**

Table 11-3: Summary of Stakeholder Involvement in MCDA for UCU

Stakeholders	Define alternatives and criteria	Make measurements	Choose decision aid	Provide preference information	Form draft solutions	Make final decision
Decision makers	X		X	X		X
Interest groups	X			X		
Experts	X	X		X		
Researcher	X	X	X		X	

Source: Author

11.4 MCDA Method Selection

Prior to value elicitation for the criteria and indicator scores and weights, clarity on **MCDA** methods applied was crucial since there are numerous **MCDA** methods applied and an understanding of the method chosen further informs value elicitation. **MCDA** methods are broadly clustered in to three main groups, which include; value/utility functions, out ranking, goal and reference.

Value/Utility function methods basically synthesise assessments of the performance of alternatives against individual criteria and inter-criteria information, giving a reflection of the relative importance of the different criteria, which in turn enables evaluation of alternatives (Belton and Stewart 2002).

Outranking methods focus on an outranking relation on the set of alternatives.

Goal and reference point method adopts a satisficing concept, which emphasises attainment of satisfactory levels of achievement on each criterion with attention shifting to other criteria once accomplished. Within the various **MCDA** methods are models which represent the decision maker's preferences and value judgments. Thus, once the **MCDA** method for application is identified, construction of some sort of model is necessary to provide support to decision makers in their search for satisfactory solutions (Belton and Stewart 2002). With reference to the **MCDA** methods briefly described, *value function method* was selected for the assessment of the sanitation systems proposed for **UCU.**

The three most prominent groups or models of aggregating the *value/utility* function methods are:

- multi-attribute value theory (**MAVT**);
- simple multiple attribute rating technique (**SMART**); and
- analytic hierarchy process (**AHP**)

Each of the three model groups have their own limitations, particularities, hypotheses, premises and perspectives which makes choosing any of the models relatively difficult to justify. However, for the sustainability assessment of sanitation system alternatives proposed for **UCU**, the **MAVT** additive model, which is also the simplest form was chosen for application (Ishizaka and Nemery 2013; Belton and Stewart 2002; Yatsalo et al. 2015). The decision to use this model was influenced by the merits of the **MAVT** model which include;

- The model helps with problem structuring by enabling the formation of a value function for preferences.
- **MAVT** enhances problem understanding.
- Furthermore, the model provides a means of communication for reasoning and negotiations by clarifying strengths and weaknesses of alternatives.
- **MAVT** also allows for incorporation of the diverse views of stakeholder groups, which can be reflected by scores and weights elicited from stakeholders.

Equation 11-1 defines the **MAVT** additive model used in this **MCDA**.

$$V(a) = \sum_{i=1}^{m} WiVi(a)$$ ………………………………………………...Equation 11-1

Where:
V(a) is the overall value of alternative ***a***
$V_i(a)$ is the value score reflecting the performance of alternative ***a*** on criterion i
W_i is the weight assigned to reflect the importance of criterion i

Despite the mentioned advantages of **MAVT** model, the main limitation is that the model assumes full compensability of criteria. As such, the criteria are all reduced and expressed in the same unit. This limitation implies that a bad performance on a criterion for instance can be compensated by good performance on another criterion and this affects the in-depth appraisal of values as well as the overall outcome (Keeney 1992). To avoid this limitation, proper understanding of value tradeoffs is crucial to decreasing the likelihood of misjudgment. After the initial model structure and set of alternatives for evaluation were identified, elicitation of value scores and weights was necessary, and was carried out as discussed in the following Sections.

11.4.1 Elicitation of Scores

Belton and Stewart (2002) define scoring as *the process of assessing the value derived by the decision maker from the performance of alternatives against the relevant criteria*. With reference to **MAVT** model, scoring means the assessment of the partial value functions $V_i(a)$. Assessment of values for the criteria should be based on an interval scale of measurement, where the *difference* between points on a scale is an important factor. Hence, definition of two reference points is necessary for construction of a scale on which numerical values can be allocated. The top or bottom points of the scale can be standardised so that 0 or 1 represents the worst outcome and a convenient value such as 10 or 100 represents the best outcome although other reference values can be used (Belton and Stewart 2002; Mabin and Beattie 2006).

In this **MCDA**, a scale of 1-10 was used with 1 representing the worst outcome and 10 representing the best outcome. Noteworthy is that the definition of the top and bottom points on the scale can be achieved in various ways although it is important to distinguish between a *local* and *global scale*. The *local* scale is defined by the set of alternatives under consideration. Thus, the alternative which registers the best result on a particular criterion is assigned a score of 100 or 10 and the one alternative which registers the least result is assigned a score of 0 or 1. All other alternatives will receive intermediate scores, which reflect their performance relative to the two end points already set. The *global* scale is defined by reference to the wider set of possibilities.

Hence, the end points may be defined by the ideal and the worst conceivable performance with regards to a particular criterion, or by the best and worst performance which could realistically occur. The definition of a *global* scale is more general than the *local scale*, which implies it could be variable applied while the *local* scale may be specific. The use of *local* scales permits a relatively quick assessment of values and can be very useful for an initial "roughing out" of a problem(Belton and Stewart 2002). The type of data used can give guidance on the choice of scale used. Mabin and Beattie (2006) further suggest that in case quantitative data is used, then either *global* or *local* scales could be used effectively. However, if qualitative data is used, then a *local* scale may be preferable. In this research, scoring of the selected indicators was carried out using *local* scales.

Moreover, since the criteria were structured in a value tree, the sanitation alternatives were scored against each of the indicators. Elicitation of scores for the indicators was accomplished by *definition of partial value functions* and *construction of qualitative scales*. In *definition of partial value functions,* a value is related to performance in terms of measurable attribute, reflecting the criterion of interest. While *construction of qualitative scales* considers assessment of the performance by reference to descriptive pointers (Belton and Stewart 2002). For both *quantitative* and *qualitative* scales used, *local* scales were applied and further description of qualitative scales is included in Appendix 6. The scores for the indicators defined using *qualitative scales* were obtained from decision makers, experts and other stakeholders. While *definition of partial value functions* was used to elicit scores for alternatives based on feasibility assessment results discussed in previous Chapters of this dissertation. Hence, the scores for specific indicators were awarded with reference to system alternative performance, reflecting the criterion of interest. In application of the *partial value functions method*, assessment of whether the value functions were monotonically increasing or decreasing against the natural scales was taken into consideration. This allowed for the computation of the *value functions* using the difference method defined by Equations 11-2 and 11-3.

The equation used when value was monotonically increasing is;

$$\boldsymbol{f^k(a_i) = \frac{f(a_i) - min(f)}{(max(f) - min(f))}}$$ ……………………………………………………………Equation 11-2

The equation used when value was monotonically decreasing is;

$$\boldsymbol{f^k(a_i) = 1 + \frac{[min(f) - f(a_i)]}{[max(f) - min(f)]}}$$ ………………………………………………Equation 11-3

Where; $f^k(a_i)$ represents the final score, $f(a_i)$ the criterion value for the specific system alternative whose score is being computed, $min(f)$ the least criterion value and $max(f)$ the highest criterion value under consideration.

Elicitation of scores from the decision makers, interest groups and experts was carried out mainly for indicators clustered under the technical and socio-cultural aspects. While the scores for indicators under environmental and economic aspects were awarded based on respective feasibility assessment results. Figure 11-4 gives an overview of how elicitation of scores was accomplished.

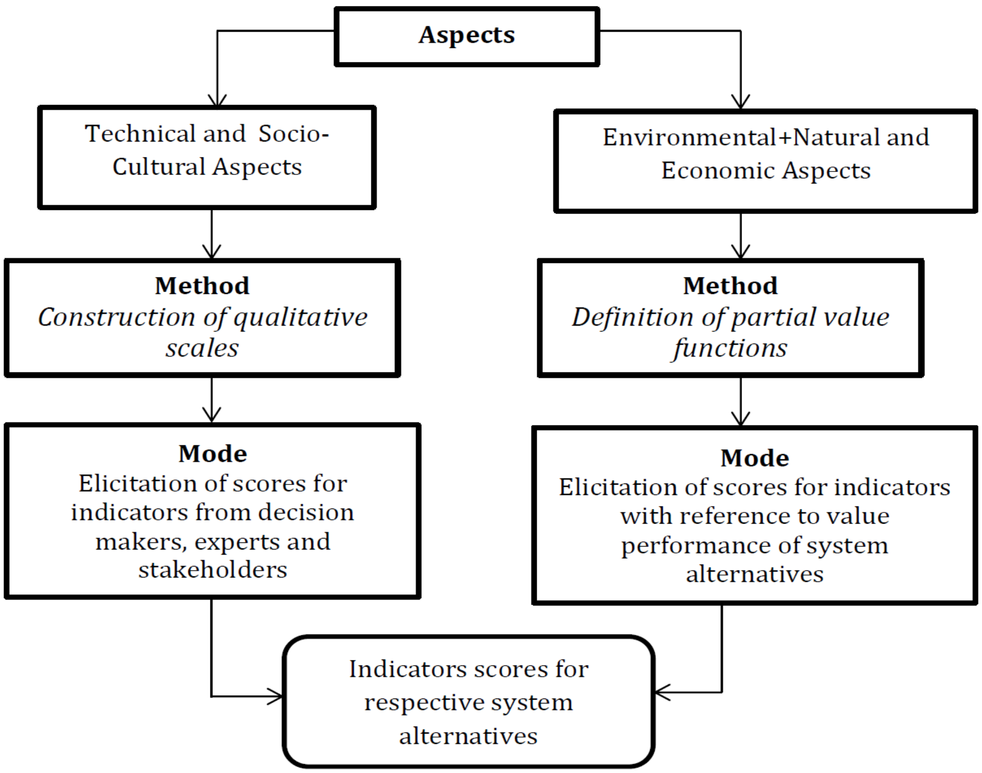

Figure 11-4: Overview of score elicitation procedure
Source: Author

Table 11-4 shows the performance of all system alternatives with reference to the selected indicator set. While Table 11-5 gives a summary of the scores awarded to various indicators for the respective system alternatives.

Table 11-4: Performance Table of Sanitation System Alternatives with Reference to Indicators

Indicators	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Additonal spacial requirement(m^2)	0	421	321	458	530	647
Global Warming Potential (kg CO_2 eq per FU)	3.28E+05	4.54E+04	4.52E+04	1.38E+05	4.07E+04	5.52E+04
Eutrophication Potential (kg PO_4^{-3}eq per FU)	258	80.9	80.9	95.3	84.1	82.5
Human Toxicity Potential (kg DCB eq per FU)	1.71E+04	1.72E+04	1.72E+04	1.56E+04	1.72E+04	1.75E+04
Energy Recovery (kWh/day)	0	1312.78	1312.78	1312.78	1746.09	3246.23
Water recovery (L/ton organic waste managed)	0	0	0	0	361.3	484.3
Nutrient recovery(kg/year)	9.4	654.2	636.1	407	207.5	180.2
Life cycle costs (UGX/year)	8,589,305	438,585,845	366,180,371	478,178,092	481,958,999	711,165,328
Benefit cost ratio	2.36	1.55	1.76	1.38	1.56	1.90
Adaptation to new conditions and requirements	70	50	50	30	30	40
Possibility utilise locally available material and skilled labour for construction	80	70	90	60	50	50
Possibility to utilise locally available labour and material for operation and maintenance of sanitation system	100	80	80	70	60	60
Sensitivity of sanitation system to shock loads	30	50	50	60	50	50
Risk of sanitation system failure	30	60	50	50	70	80
Perception	88	88	100	77	70	50
Convenience	50	58	50	50	83	67

Source: Author

Where **FU** represents the functional unit used for comparison of sanitation system alternatives (refer to Chapter 8)

Table 11-5: Indicator Value Function with Reference to 1-10 Scale

Indicators	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Land required	10.0	3.5	5.0	2.9	1.8	1.0
Global warming potential	1.0	9.8	9.8	6.6	10.0	9.5
Eutrophication Potential	1.0	10	10	9.2	9.8	9.9
Human Toxicity Potential	2.1	2.1	2.1	10	2.1	1.0
Energy Recovery	1.0	4.0	4.0	4.0	5.4	10
Water recovery	1.0	1.0	1.0	1.0	7.5	10
Nutrient recovery	1.0	10.0	9.7	6.2	3.2	2.8
Life cycle costs	10.0	3.9	4.9	3.3	3.3	1.0
Benefit cost ratio	10.0	2.0	4.0	1.0	2.0	5.3
Adaptation to new conditions and requirements	10.0	5.0	5.0	1.0	1.0	2.5
Possibility utilise locally available material and skilled labour for construction	7.5	5.0	10	2.5	1.0	1.0
Possibility to utilise locally available labour and material for operation and maintenance of sanitation system	10.0	5.0	5.0	2.5	1.0	1.0
Sensitivity of sanitation system to shock loads	10.0	3.3	3.3	1.0	3.3	3.3
Risk of sanitation system failure	10	4.0	6.0	6.0	2.0	1.0
Perception	7.6	7.6	10	5.4	4.0	1.0
Convenience	1.0	2.4	1.0	1.0	10	5.2

Source: Author

Note: Computation of the indicator values functions was carried out with reference to local scale using Equations 11-2 and 11- 3.

Once the scores for the various indicators were obtained, elicitation of weights was carried out to enable complete evaluation of alternatives with reference to **MAVT** additive model.

11.4.2 Elicitation of Weights

The "weight" basically represents the relative importance attached to a criterion or indicator. Attachment of weights to criteria is based on the understanding that not all criteria bear the same level of importance. Thus, incorporation of the relative significance is reflected in the "weights" assigned. The weight assigned to a particular criterion represents a scaling factor which relates scores on that criterion to scores on all other criteria. The swing method of weight assessment may be used when criteria are represented using a value tree. The swing weights capture both the concept of "importance" and the extent to which the measurement scale adopted discriminates between alternatives (Belton and Stewart 2002; Mabin and Beattie 2006). The swing considers variation from the worst value to the best value on each criterion. Once the extreme values have been assigned, the remaining criteria are also defined by ranking of the criteria weights. This is accomplished by assessment of the relative value of the swings (Belton and Stewart 2002).

In the event that a **MCDA** problem is structured as a multi-level value tree which was the case for **UCU**, the weights should be assigned at different levels of the tree. The relative weights are then assessed within families of criteria i.e. criteria sharing the same parent. Normalisation of the weights from each family would then be accomplished. Thereafter, computation of the cumulative weight of a criterion would then be accomplished by finding the product of its relative weight in comparison with its siblings and the relative weights of its parent and so on to the top of the tree (Belton and Stewart 2002).

Similar to score elicitation, the assignment of weights to the indicators, criteria and aspects represented in the value tree was accomplished by decision makers, interest groups and experts, using the swing method. Elicitation of stakeholder input was accomplished using questionnaires which were sent out and returned by email. A copy of the weight elicitation questionnaire is included in Appendix 5. Variable weights assigned to indicators, criteria and aspects by decision makers and experts were also used for sensitivity analysis discussed in Section 11.6. Figure 11-5 gives an overview of the weights assigned to the aspects, criteria and indicators as shown in **V.I.S.A** software which was used for evaluation of the sanitation system alternatives.

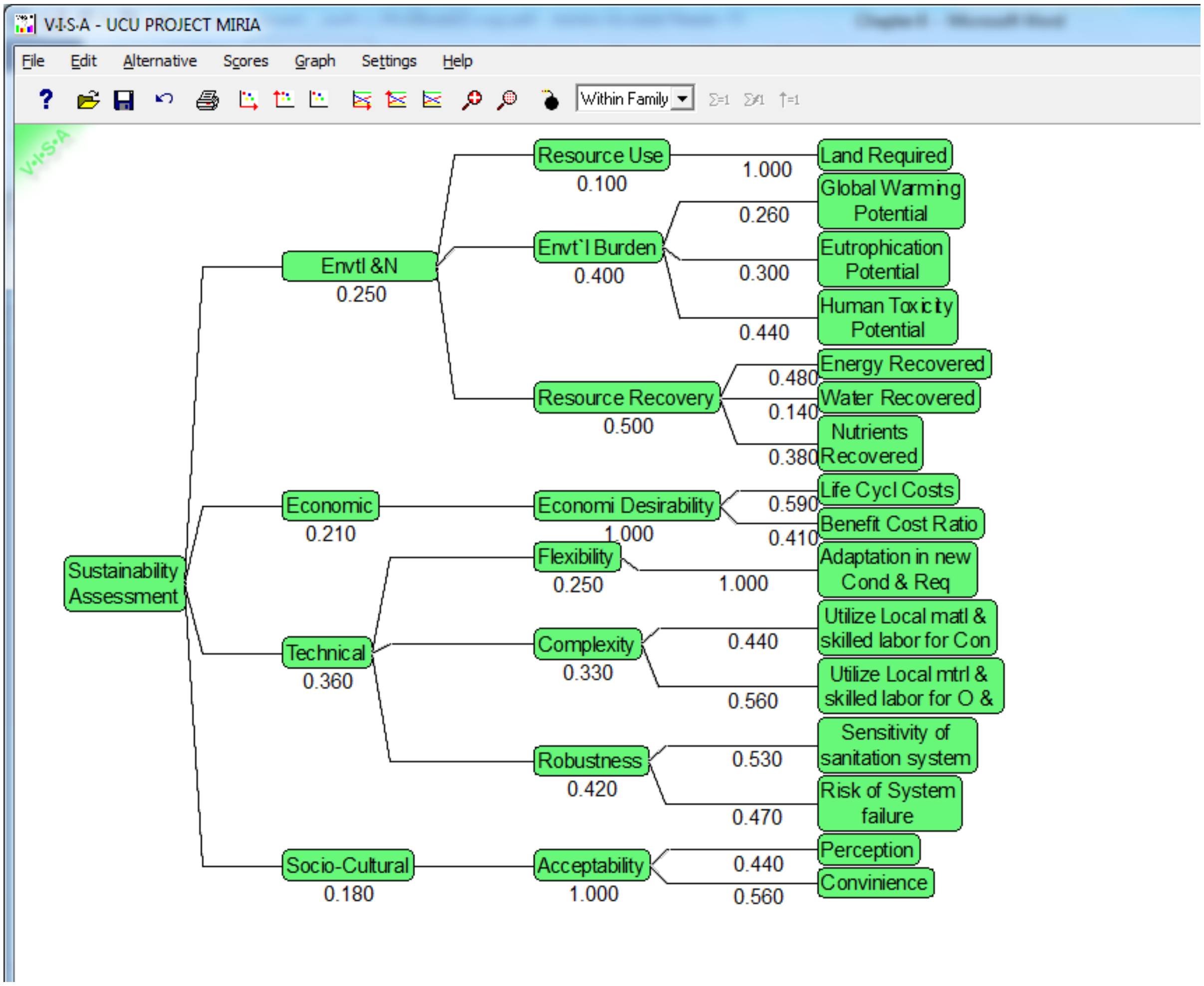

Figure 11-5: Screenshot showing weights assigned at different levels of the value tree.
Source: V.I.S.A Software

11.5 Evaluation of System Alternatives

The overall evaluation of the system alternatives was accomplished by first multiplying the value scores on indicators by the cumulative weight of that particular indicator and this was followed by aggregation of the resultant values with reference to Equation 1 (Belton and Stewart 2002; Mabin and Beattie 2006). This computation was accomplished using **V.I.S.A** software.

11.5.1 MCDA Results

Computation of the overall sustainability values for each of the sanitation system alternatives is summarised in Figure 11-6.

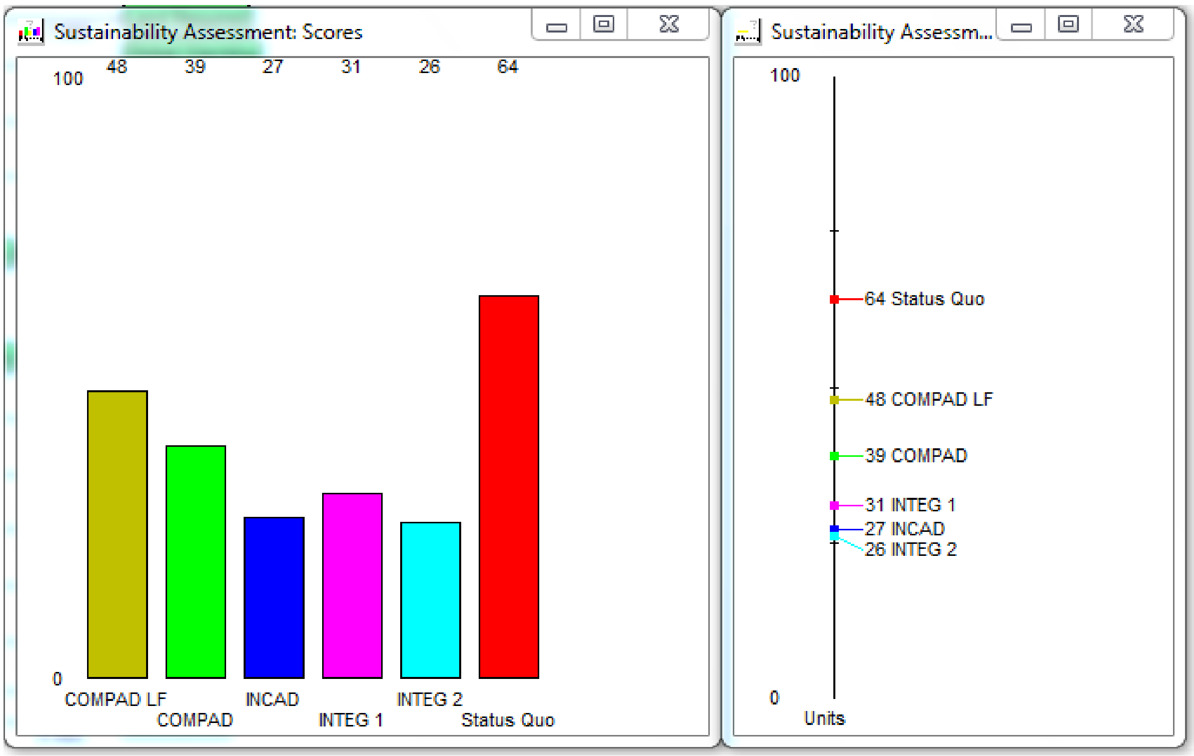

Figure 11-6: Screenshot showing overall sustainability performance of system alternatives
Source: Author

From Figure 11-6, the overall sustainability results trend showed that the **Status Quo** alternative registered the highest value of 64 and was followed by the **COMPAD LF** alternative at 48**, COMPAD** at 39, **INTEG 1** at 31**, INCAD** at 27 and finally the **INTEG 2** alternative with a value of 26. A difference of up to 18 points can be traced between the **Status quo** alternative and **COMPAD LF.** While a difference in sustainability values of 9 points was registered between the **COMPAD LF** and **COMPAD** alternatives as well as between the **COMPAD** and **INTEG 1** alternatives. The sustainability value for the **Status Quo** alternative was above 50. While the **COMPAD LF** alternative was only 2 points short of the 50 point mark. Meanwhile all other sanitation alternatives registered much lower sustainability values as shown in Figure 11-6. To fully appreciate the implications of these results, assessment of individual profiles was carried out. Profiles basically show the values for each alternative with reference to all indicators within the selected family. The assessment of profiles was carried out at aspect level, giving details about the contributions from respective criteria.

11.5.1.1 Environmental and Natural Resource Aspect;

An overall assessment of sanitation system alternatives with reference to the environmental and natural resources aspect showed that the **INTEG 2** alternative registered the highest value of 57 followed closely by the **COMPAD LF** and **INCAD** alternatives at 56, then **COMPAD** at 55, **INTEG 1** at 46 and finally **Status Quo** at 12. For all the integrated sanitation system alternatives, sustainability values of at least 46 were registered. With reference to specific criteria, the assessment showed that the **Status Quo** alternative performed excellently in terms of resource use, although it had the highest environmental burden and the least resource recovery as shown in Figure 11-7.

Still with regards to resource use, the **COMPAD LF** alternative performed better than the **COMPAD** alternative**,** which was then followed by the **INCAD** alternative, **INTEG 1** and finally **INTEG 2** alternative**.** When the environmental burden criterion was considered, the **INCAD** alternative registered the highest result of 88, while all the three alternatives **COMPAD**, **COMPAD LF** and **INTEG 1** registered the same result of 61. The **INTEG 2** alternative also registered a moderate result of 56 while the **Status Quo** alternative registered the least result of only 5. Finally, with reference to the resource recovery criterion, the **INTEG 2** alternative registered a result of 70, the **COMPAD** and **COMPAD LF** registered the same result at 54, **INTEG 1** at 41 and the **INCAD** alternative at 37. Noteworthy was that for all three criteria within this aspect, the **COMPAD** and **COMPAD LF** alternatives registered moderate values and this eventually influenced their overall performance with respect to this aspect.

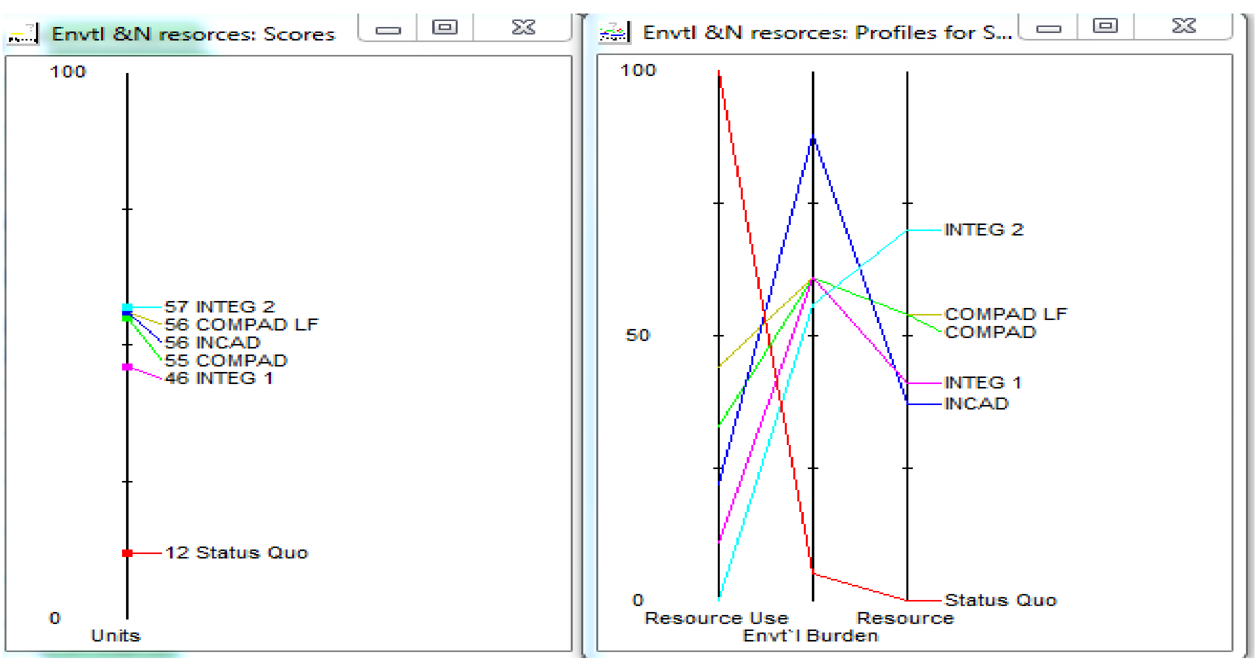

Figure 11-7: Screenshots showing the environmental and natural resources scores and profile for the sanitation system alternatives

Source: V.I.S.A Software

The variation in results for the system alternatives illuminated the fact that based on the priorities considered, any of the sanitation system alternatives could be preferred. The high results registered by the **Status Quo** alternative with reference to the resource use criterion were because no additional land would be required within the University for the any installation/upgrade of the system alternative. The structural modifications considered for the sanitation system only included incorporating a roofing structure to the existing lagoons. Meanwhile, in case the least environmental burden was opted for, then the **INCAD** alternative would be preferred although the **COMPAD, COMPAD LF** and **INTEG 2** alternatives could additionally be considered since they also registered sustainability values of at least 56. Alternatively, if a tradeoff between resource recovery and environmental burden was considered, then the **INTEG 2** alternative would be the most preferred alternative followed by **COMPAD** and **COMPAD LF** alternatives**.** In case moderate performance with respect to both environmental burden and resource recovery criteria was considered, then the **COMPAD** and **COMPAD LF** alternatives would fulfill the requirements since both alternatives perform moderately for both criteria.

11.5.1.2 Economic Aspect

With reference to the economic aspect, the overall trend showed that the **Status Quo** alternative registered the highest result of 100 followed by the **COMPAD LF** at 40**,** the **COMPAD** alternative at 24, **INTEG 1** at 18 and the **INCAD** registered a result of 13 as shown in Figure 11-8. Noteworthy was that all sanitation system alternatives registered sustainability results lower than 50 except for the **Status Quo** alternative. Given that the *economic desirability* criterion was represented by *life cycle costs* and *benefit cost ratio* indicators described in Section11.2.4.2*,* an assessment of the profile showed that the **Status Quo** alternative registered very high results with reference to both indicators as compared to all other sanitation system alternative. The high score of the **Status Quo** alternative was attributed to the fact the alternative had much *lower life cycle costs* in comparison to other alternatives. The main costs for the **Status Quo** alternative included the costs that would be incurred for modification of the lagoon as already discussed and operation costs which would be incurred in handling and transportation of the sewage sludge from the lagoons for further management. Moreover, the alternative also had a much higher *benefit cost* ratio in comparison to other alternatives. The high *benefit cost ratio* was influenced by the much lower overall costs incurred by the **Status Quo** alternative.

For the remaining system alternatives, interesting trends of performance were noted since all these alternatives had much higher *life cycle costs* than the **Status Quo** alternative as discussed in Chapter 9 of this dissertation and also indicated in Table 11-4. The results trend with reference to the *life cycle costs* showed that **COMPAD LF>COMPAD>INTEG 1** and **INCAD>INTEG 2.** The much better performance to the **COMPAD LF** alternatives in comparison to other integrated sanitation system alternative was additionally attributed to the slightly lower *life cycle costs* incurred by the system. The fact that utilisation of an existing composting plant at Mukono Municipal landfill was considered for this alternative implied that installation costs for a new composting plant were avoided, reducing overall *life cycle costs* of the **COMPAD LF** alternative.

Meanwhile, with reference to the *benefit cost ratio,* the trend showed that **INTEG 2**> **COMPAD LF> COMPAD and INTEG 1** >**INCAD.** In spite of the high *life cycle costs* incurred by the **INTEG 2** alternative, the higher revenues accrued from additional resource recovery contributed to a much higher *benefit cost ratio* for the alternative. For the **INTEG 2** alternative, additional resource recovery in the form briquettes from digestate was considered.

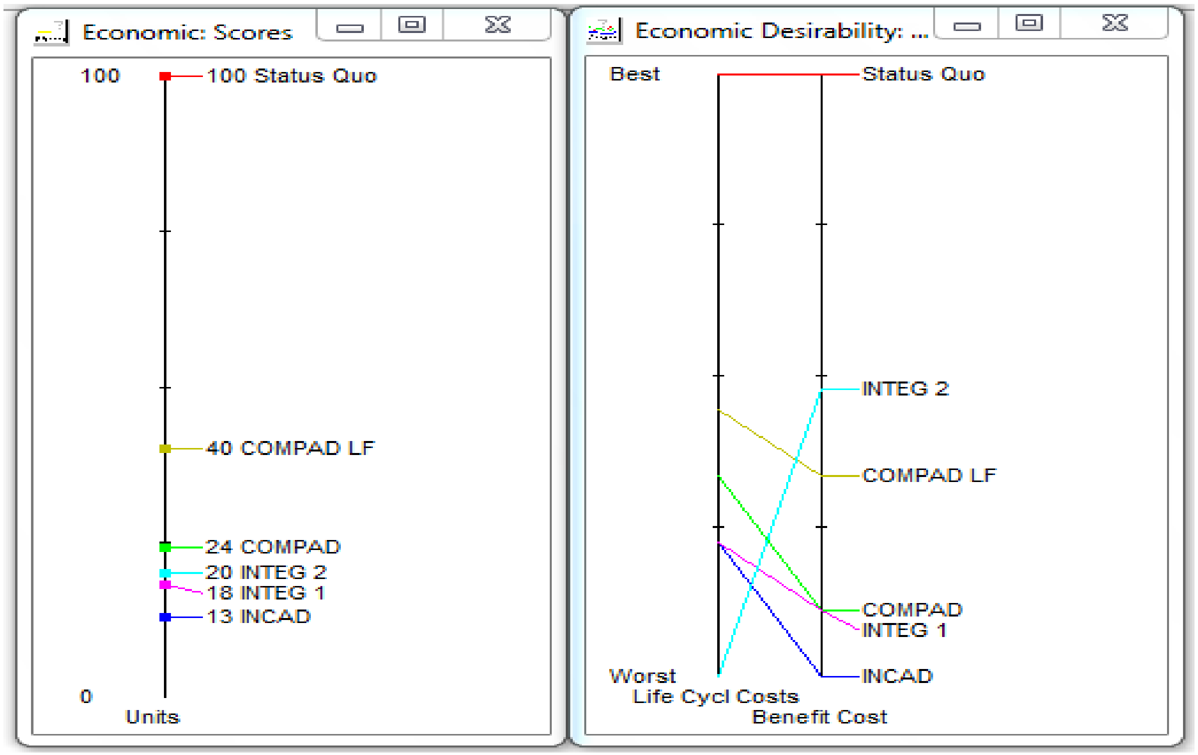

Figure 11-8: Screenshots showing the economic aspects scores and profile for the sanitation system alternatives
Source: V.I.S.A Software

11.5.1.3 Technical Aspects

With reference to the technical aspects, the **Status Quo** alternative registered the highest result of 96 followed by the **COMPAD LF** at 50, **COMPAD** at 37, **INCAD** at 17, **INTEG 2** at 9 and **INTEG 1** at 7. The overall high results registered by the **Status Quo** were due to the fact that the alternative registered high values with regards to all criteria i.e. flexibility, complexity and robustness registering. Variability in results with reference to the three criteria was noted for the sanitation system alternatives with the **COMPAD LF** and **COMPAD** sharing the same result with regards to the *flexibility* criterion. Both sanitation systems were considered to have the same level of adaptability in case any modifications or upgrading was considered. Meanwhile, the **INTEG 1** and **INTEG 2** alternatives also registered the same result with reference to *complexity* criterion. Figure 11-9 shows the technical aspect and criteria profiles for the respective sanitation system alternatives.

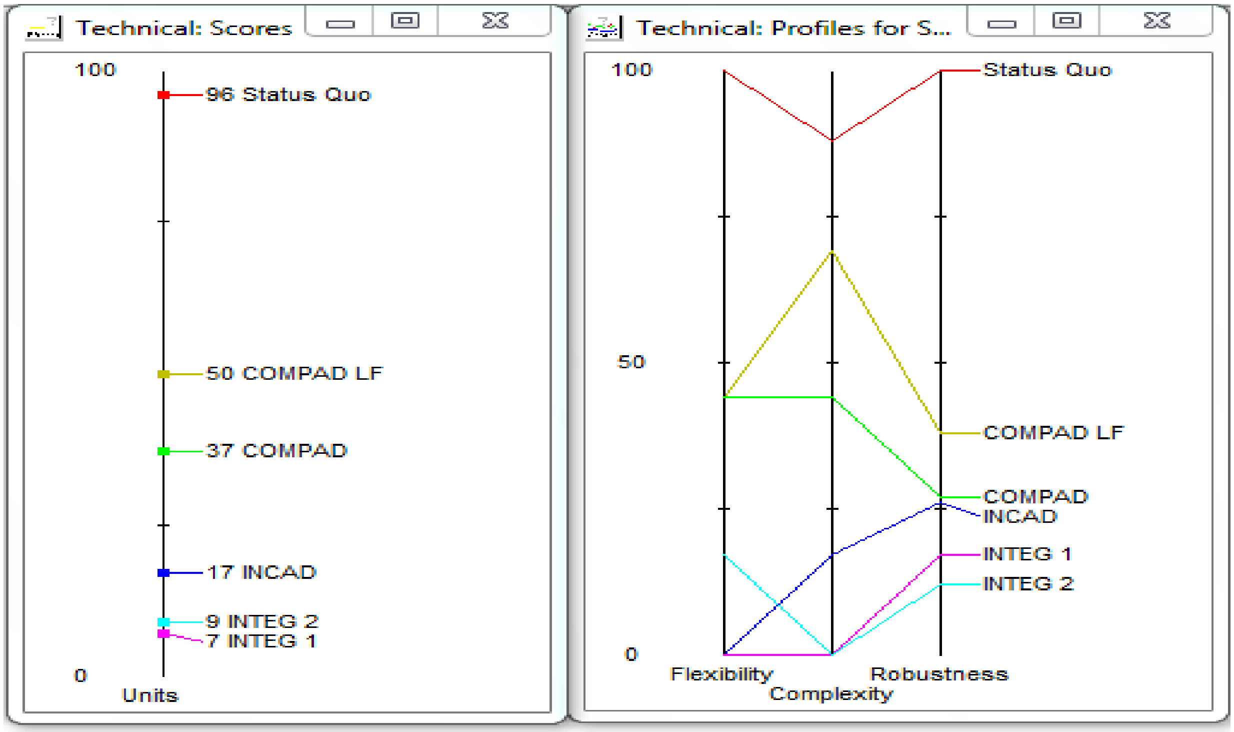

Figure 11-9: Screenshots showing the technical aspects scores and profile for the sanitation system alternative
Source: V.I.S.A Software

In the **Status Quo** alternative, sewage sludge is mainly managed by disposal in the lagoon for a duration of one year. The alternative also takes into account possibility of further handling of the partially stabilised sewage sludge at other treatment plants. Meanwhile, the kitchen waste was used as animal feed and cow dung used as soil conditioner or dumped in the cattle kraal. Based on such organic waste management measures, the alternative was considered much less complex and more robust than the other alternatives, which additionally considered an anaerobic digestion process. Anaerobic digestion was considered quite complex and less robust since it depends on environmental factors i.e. substrates used, temperature, and pH among others. Moreover, the **Status Quo** alternative was considered highly flexible since other alternatives proposed were designed with reference to the existing system (refer to Chapter 7).

The much better results of the **COMPAD LF** alternative in comparison to **COMPAD** alternative with reference to *complexity* and *robustness* criteria was attributed to the fact that the Mukono Municipal composting plant is already operational. Thus, the required human resource for various operation and maintenance activities, in addition to readily available organic waste would be guaranteed and this would positively influence the robustness of the **COMPAD LF** alternative. The much better results of the **COMPAD LF** and **COMPAD** alternatives in comparison to **INCAD, INTEG 1** and **INTEG 2** alternatives were influenced by their performance with respect to *robustness* and *complexity criteria*.

With reference to the designs of the **COMPAD** and **COMPAD LF** alternatives, failure of a component within the sanitation system would not affect the entire system. For instance, any operational failure within the anaerobic digestion unit would not affect the composting unit hence, moderate performance of the sanitation system can still be expected. A similar explanation holds with regards to the system robustness, which was defined by *sanitation system sensitivity*. While by the nature of the designs for the **INTEG 1** and **INTEG 2** alternatives, these sanitation systems were generally considered less *robust* and *flexible* since any operational failure in the anaerobic digestion unit would affect other processes within the whole system.

11.5.1.4 Socio-Cultural Aspects

The profile for socio-cultural aspects showed that the **INTEG 1** alternative registered the highest result of 71 followed by the **COMPAD LF** at 44**, COMPAD** at 41, **Status Quo** at 32, **INTEG 2** at 26 and **INCAD** at 22. The high level of *convenience* attached the **INTEG 1** alternative contributed to its overall high result with reference to the socio-cultural aspect. While the low level of *convenience* attached to the **Status Quo** and **INCAD** alternatives also influenced to their overall results with respect to this aspect.

On the other hand, the better performance of the **COMPAD** and **COMPAD LF** alternatives in comparison to the **Status Quo, INCAD** and **INTEG 2** alternatives was attributed to the high level of *convenience* attached to the system alternatives. Despite registering low results with reference to the *level of convenience* attached, the high results with reference to *perception* for the **COMPAD LF** alternative contributed to an overall better result for the acceptability criterion in comparison to the **COMPAD** alternative**.** The fact that the composting plant at the Mukono Municipal landfill is already operational implied that any challenges associated with inexperience in operation would be reduced. Moreover, availability of readily available additional organic waste at the landfill, which is considered a driving factor for composting waste, further influenced the *perception* towards the **COMPAD LF** alternative. Figure 11-10 shows the socio-cultural aspect and acceptability profiles for the sanitation system alternatives**.**

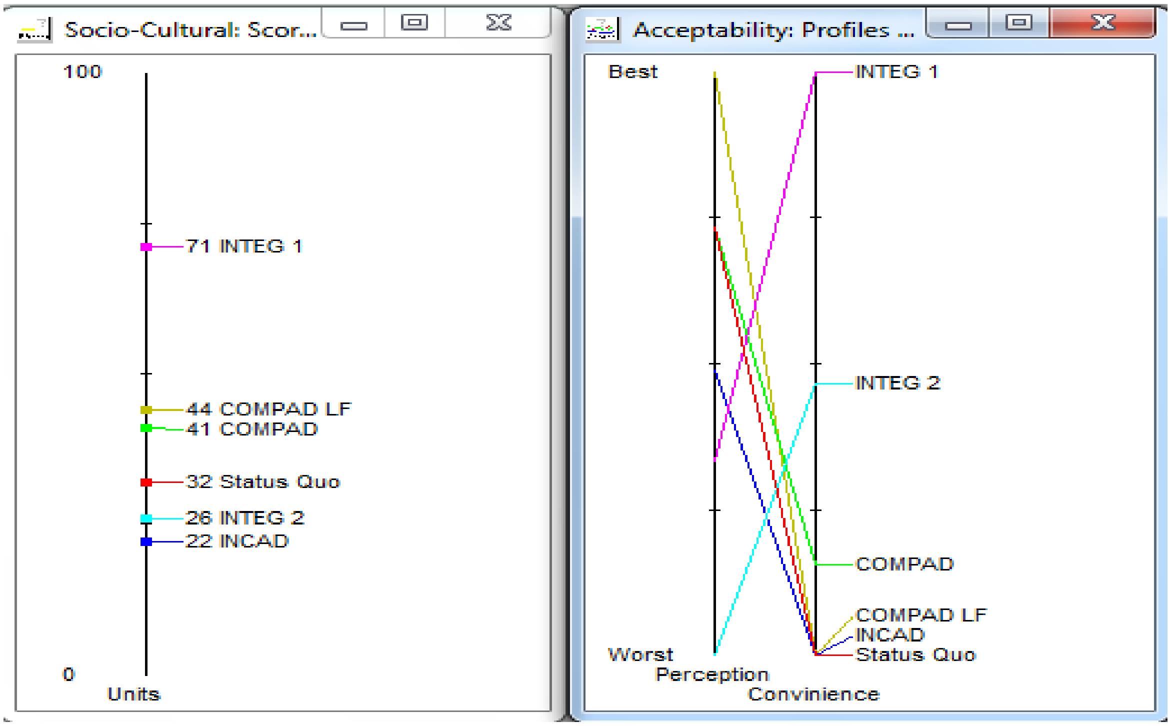

Figure 11-10: Screenshots showing the socio-cultural aspect scores and profile for the sanitation system alternatives
Source: V.I.S.A

11.5.2 Discussion of Results

The assessment of profiles for the four sustainability aspects showed variable performance for the sanitation system alternatives. Environmental and natural resources aspects showed that the **Status Quo** alternative registered the highest results in comparison to other alternatives when the resource use criterion was taken into account. The high results registered by the **Status Quo** alternative was attributed to the fact that additional installations/upgrade considered for the system alternative consisted mainly of infrastructural modifications for the already existing lagoons at the **UCU** Wastewater Treatment Plant (WWTP). As such, no additional land/space within the University was required for the system upgrade/installation. Meanwhile, all other alternatives required additional space where other system components/units such as the composting plant, anaerobic digester and solar drying unit among others would be installed.

With reference to other criteria within the Environmental aspects i.e. *environmental burden* and *resource recovery* criteria, all integrated sanitation system alternatives registered much higher results than the **Status Quo** alternative. Particularly with reference to the *environmental burden* criterion, the **INCAD** alternative registered the highest result while the **INTEG 2** alternative registered the highest result when the *resource recovery* criterion was considered. The overall good performance of the **INCAD** alternative with reference to the *environmental burden* was additionally influenced by the much lower human toxicity potential registered by the system alternative in comparison to other system alternatives.

The additional emission control measures incorporated within the incineration unit implied that toxic emissions to the environment were checked thus, in comparison to other sanitation system alternatives, the human toxicity potential of the **INCAD** alternative was much lower. Meanwhile, the good performance of the **INTEG 2** alternative in terms of *resource recovery* was further attributed to the proposed production and utilisation of briquettes from digestate. This implied that in addition to *resource recovery* in the form of biogas and organic fertilizer from digestate common to other integrated sanitation system alternatives, the **INTEG 2** alternative additionally considered recovery of briquettes from digestate.

The economic aspects profile showed that the **Status Quo** alternative registered the highest overall result followed by the **COMPAD LF** and **COMPAD** alternatives registering sustainability values of at least 24. The remaining sanitation system alternatives i.e **INTEG 2, INTEG 1**and **INCAD** had results in the range of 13-20. Except for the **Status Quo** alternative, all other sanitation system alternatives registered values lower than 50. The high results for the **Status Quo** alternative with respect to this aspect was attributed to the fact the alternative had much lower *life cycle costs* in comparison to other alternatives. Moreover, since the alternative had much lower *life cycle costs*, a much higher *benefit cost ratio* in comparison to other alternatives was also registered. With reference to the **COMPAD LF, COMPAD, INCAD, INTEG 1** and **INTEG 2** alternatives, the much better performance of the **COMPAD LF** alternative was additionally attributed to the lower *life cycle costs* incurred by the system. Utilisation of an existing composting plant at Mukono Municipal landfill for the **COMPAD LF** alternative implied that installation costs for a new composting plant were avoided, reducing overall *life cycle costs* of the system.

With reference to the technical aspects, the **Status Quo** alternative registered the highest result in comparison to other system alternatives for all three criteria i.e. *flexibility, complexity* and *robustness*. Moreover, the **COMPAD LF** and **COMPAD** alternatives also registered much better results in comparison to the **INCAD, INTEG 1** and **INTEG 2** alternatives with reference to all three criteria. For the **Status Quo** alternative, the organic waste management measures were considered to be much less complex and more robust in comparison to the measures considered for other sanitation system alternatives. For all the integrated sanitation system alternatives, anaerobic digestion process was additionally considered. Moreover, the **Status quo** alternative was considered highly flexible since other proposed alternatives were designed with reference to the existing system

Meanwhile, the better results for **COMPAD LF** alternative in comparison to the **COMPAD** alternative with reference to *complexity* and *robustness* criteria was attributed to the fact that Mukono Municipal composting plant is already operational. Thus, the required human resource for various operation and maintenance activities in addition to readily available organic waste would be guaranteed. Moreover, the much better results of **COMPAD LF** and **COMPAD** alternatives in comparison to **INCAD**, **INTEG 1**and **INTEG 2** were further contributed to the much higher robustness and lower complexity associated with the system alternatives.

Based on the system designs of the **COMPAD** and **COMPAD LF** alternatives, failure of a component within the sanitation system would not affect the entire system. For instance, any operational failure within the anaerobic digestion unit would not affect the composting unit hence, partial performance of the sanitation system can still be expected. A similar explanation holds with regards to the system robustness, which was defined by *sanitation system sensitivity*. While by the nature of the designs for the **INTEG 1** and **INTEG 2** alternatives, the sanitation systems were generally considered less *robust* and *flexible* since any operational failure in the anaerobic digestion unit would affect other connecting processes within the whole system. Other unit processes that would be affected include the solar drying unit considered for drying digestate and the briquetting unit used to make briquettes from dried digestate.

The performance of the sanitation system alternatives with reference to the socio-cultural aspects showed that the **INTEG 1** alternative had the highest result in comparison to other alternatives, registering a margin of 27 points. The high level of *convenience* attached the **INTEG 1** alternative contributed to its overall high result while the low level of *convenience* attached to the **Status Quo** and **INCAD** alternatives also influenced to their overall results with respect to this aspect. Moreover, the good performance of the **INTEG 1** alternative was further attributed to the system`s design, which considered combined management of organic waste streams using anaerobic digestion. In addition, further treatment of digestate by solar drying was seen to cater for any anticipated inconveniences. Thus, odour and risk of pathogen exposure from utilisation of digestate as organic fertilizer would be catered for and this contributed to high level of *convenience* attached to the alternative.

Furthermore, the better performance of the **COMPAD** and **COMPAD LF** alternatives in comparison to the **Status Quo, INCAD** and **INTEG 2** alternatives was attributed to the high level of *convenience* attached to the system alternatives. In comparison to the **Status Qu**o alternative, the **COMPAD LF** and **COMPAD** alternatives were considered more convenient since the systems further managed sewage sludge from the lagoons while additionally recovering resources (compost, biogas, digestate as organic fertilizer). The fact that the compositing plant at Mukono Municipal landfill is already operational implied that any challenges associated with inexperience in operation would be reduced. Moreover, availability of readily available additional organic waste at the landfill, which is considered a driving factor for composting waste, further influenced the better *perception* towards the system. In comparison to the **INCAD** alternative, the **COMPAD LF** and **COMPAD** alternatives were considered more convenient since experiences related to composting of organic waste already exist within Mukono Municipal landfill.

From the assessment of individual profiles discussed, it was evident that no single sanitation system alternative completely dominated other alternatives with respect to all sustainability aspects considered. Instead, variation in the performance of the alternatives was observed, implying that preference of alternatives could occur be based on tradeoffs.
Although the overall sustainability values are an indicator of the largeness of the alternative, these values do not show the relative efficiency.

Trade-offs between aspects or criteria allows for visualisation of relative efficiency, which can be expected in sustainability assessments since inter-linkages between aspects or pillars exists. As such, when trade-offs between the four aspects were considered, results indicated that different sanitation system alternatives were selected while other alternatives lay within the efficient frontier[21]. The alternatives that lay within the efficient frontier were considered to perform relatively well. Moreover, the sanitation system alternatives that missed the efficient frontier but also represented better balanced decision were referred to as those positioned within the "linearity trap" region. These alternatives could also be considered with reference to the trade-offs made since their performance was slightly below the selected alternatives. Meanwhile, alternatives were considered as dominated when other alternatives scored better than them in every criterion (Belton and Stewart 2002; Mabin and Beattie 2006). Table 11-6 shows a summary of the trade-offs between aspects considered.

Table 11-6: Summary of trade-offs between aspects for sanitation system alternatives

Trade-off	Selected alternative	Alternative within efficient frontier	Alternative within linearity trap
Environmental-Economic	COMPAD LF	Status Quo	
Environmental-Technical	COMPAD LF	Status Quo	COMPAD
Environmental-Socio-Cultural	COMPAD LF	INTEG 1	COMPAD
Economic-Technical	COMPAD LF	Status Quo	COMPAD
Economic-Socio-Cultural	INTEG 1		
Economic-Environmental	COMPAD LF	INCAD, INTEG 2, COMPAD	INTEG 1
Technical-Socio-Cultural	COMPAD LF	INTEG 1	COMPAD, Status Quo
Technical-Economic	COMPAD LF	Status Quo	COMPAD, INTEG 2, INTEG 1
Technical-Environmental	COMPAD LF	INCAD, COMPAD, INTEG 2	INTEG 1
Socio-Cultural-Technical	COMPAD LF	Status Quo	COMPAD
Socio-Cultural-Economic	COMPAD LF	Status Quo	
Socio-Cultural-Environmental	COMPAD LF	INCAD INTEG 2, COMPAD	INTEG 1

Source: V.I.S.A

For most of the trade-offs between aspects considered, the **COMPAD LF** alternative is the most selected alternative while variable alternatives lie within the efficient frontier i.e. **COMPAD** and **INTEG 1** alternatives. From the assessment of trade-offs summarised in Table 11-6, it can be concluded that the **COMPAD LF** alternative can be relied on since for most trade-offs considered, the alternative is selected.

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[21] Efficient frontier; is a mathematical concept that evaluates the expected returns, standard deviation and the covariance of a set of securities to determine which combinations, or portfolios, generate the maximum expected return for various levels of risk (Markowitz 1952).

Meanwhile, a pattern can be traced that for any trade off consisting of economic and technical aspects, the **Status Quo** alternative lies within the efficient frontier. Moreover, no alternative was dominated since all the alternatives appeared at least once within the efficient frontier for all tradeoffs considered. This implied that no alternative was eliminated from further analysis, which involved a sensitivity analysis.

11.6 Sensitivity Analysis

A sensitivity analysis was carried out to check if the **MCDA** results obtained were robust or sensitive to any changes in aspects of the model used. Belton and Stewart (2002) suggest that sensitivity analysis in **MCDA** can be categorised according to three perspectives i.e. *technical, individual* and *group*. The *technical perspective* focuses on objective examination of the influence on the output of a model if changes in the input parameters of the model are considered. Thus, input parameters such as value functions, scores and weights as determined by the decision makers are varied. The output of such variation in scores and weights should allow for overall evaluation of alternatives. Sensitivity analysis with reference to the *individual perspective* mainly provides a basis against which tests for individual intuition and understanding of the problem can be achieved. While sensitivity analysis based on the *group perspective* allows for exploration of alternative perspectives on the problem, which is often captured by different sets of criteria weights (Belton and Stewart 2002).

For the sensitivity analysis of the sanitation systems alternatives proposed for **UCU**, a combination of *technical* and *group perspectives* were considered. Taking into account that elicitation of scores and weights was accomplished through a combination of methods, three scenarios for sensitivity analysis were considered.

Scenario 1

This scenario took into consideration the variation of *perception* and level of *convenience* scores assigned to the sanitation system alternatives by using results from the stakeholder survey discussed in Chapter 10 instead of the base case considerations. In the base case scenario, input for *perception* and *convenience* scores was obtained from lecturers, technical staff at **UCU**, interest groups and experts. Thus, for **Scenario 1** the input for *perception* and *convenience* scores was obtained from **UCU** stakeholder surveys while input for other indicators was maintained as in the base case scenario. The sensitivity analysis reflected a combination of *group* and *technical perspectives.*

Scenario 2

Here, the variation of scores assigned by selected lecturers, technical staff from **UCU**, interest groups and experts was considered. Specifically, variation to incorporate low scores assigned to the indicators clustered under technical and socio-cultural aspects was considered. Similar to **Scenario 1**, a combination of *group and technical perspectives* were reflected during the sensitivity analysis.

Scenario 3

Scenario 3 mainly took into account variation of weights assigned to indicators by the lecturers, technical staff at **UCU**, interest groups and experts and a categorisation of the weights as low and high values was considered.

Since the weights were mainly assigned to aspects, criteria and indicators by the same group of stakeholders, this scenario reflected a *group perspective*.

11.6.1 Sensitivity Analysis Results

Table 11-7 shows a summary of the scores for level of *convenience* and *perception* indicators derived from the stakeholder survey used in computation of **Scenario 1** during the sensitivity analysis**.**

Table 11-7: Value Functions for Perception and Convenience Derived from Stakeholder Survey

Indicators	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Level of Convenience	10	6.7	6.7	3.3	1	1
Perception	1	10	10	9.6	9.7	5.8

Source: Stakeholder Survey **-UCU**

11.6.2 Sensitivity Analysis Results: Scenario 1

The sensitivity analysis results for scenario 1 still showed that the **Status Quo** alternative had the highest sustainability value of 69 followed by the **COMAPD LF** alternative at 55, **COMPAD** at 46, **INCAD** at 33 while the **INTEG 1** and **INTEG 2** alternatives both registered sustainability values of 26. In comparison to the base case scenario, the **Status Quo** alternatives registered 4 points more while the **COMPAD LF** and **COMPAD** alternatives registered 7 points more. Moreover, the **COMPAD LF** alternative registered a sustainability value more 50 while the **COMPAD** alternative was only 4 points short of 50. As such, in addition to the **COMPAD LF** alternatives, the **COMPAD** can also be considered to perform moderately with reference to this scenario.

This time round the **INCAD** alternative also registered a better sustainability result than the **INTEG 1** alternative by a difference of 7 points although in the base case scenario, the **INTEG 1** alternative performed better than **INCAD** by 4 points. Moreover, in this scenario, the **INTEG 2** and **INTEG 1** alternatives both registered the same value and held the last position in the performance trends. A closer look at the socio-cultural aspect profile showed a variation in performance from **INTEG 1>COMPAD LF>COMPAD>Status Quo>INTEG 2>INCAD** in base case scenario to **COMPAD LF and COMPAD> INCAD and Status Quo>INTEG 1>INTEG 2** when **Scenario 1** was considered. The **COMPAD LF** and **COMPAD** alternatives registered a value of 79 when Scenario 1 was considered as compared to only 44 in the base case scenario. The high level of *convenience* attached to the **Status Quo** alternative in this scenario also contributed to its much better overall performance of the system in comparison to when the base case scenario was considered.

The high level of *convenience* attached to the **Status Quo** alternative during the survey was partly attributed to the fact that further management of sewage sludge from the lagoon would be carried out a way from **UCU**(refer to Chapter 10). Figure 11-11 shows sustainability performance of the sanitation system alternatives based on Scenario 1 conditions.

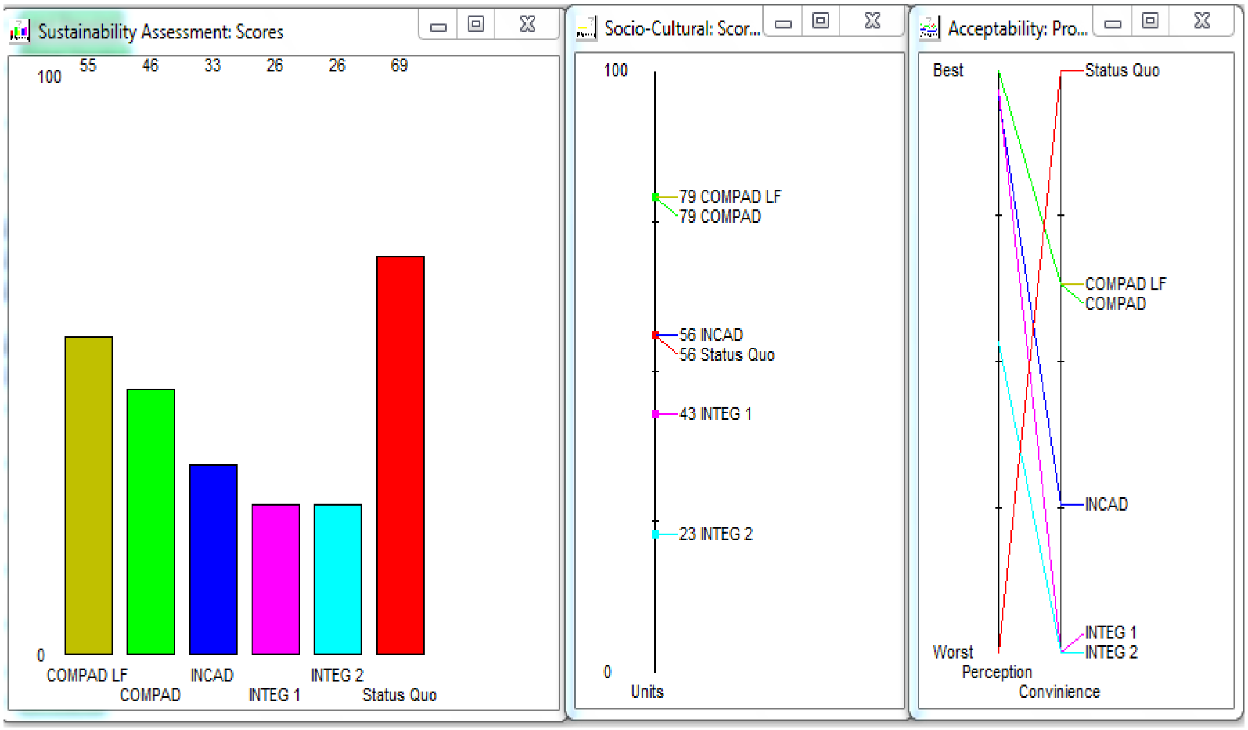

Figure 11-11: Screenshots showing sustainability scores and profiles for sanitation system alternatives with reference to Scenario 1
Source: V.I.S.A Software

11.6.3 Sensitivity Analysis Results: Scenario 2

A sensitivity analysis to check the influence of lower value scores assigned to indicators within the technical and socio-cultural aspects by selected lecturers, technical staff at **UCU** interest groups, experts showed a performance trend of **Status Quo>COMPAD LF>COMPAD>INTEG 1 and INCAD>INTEG 2** as shown in Figure 11-12.

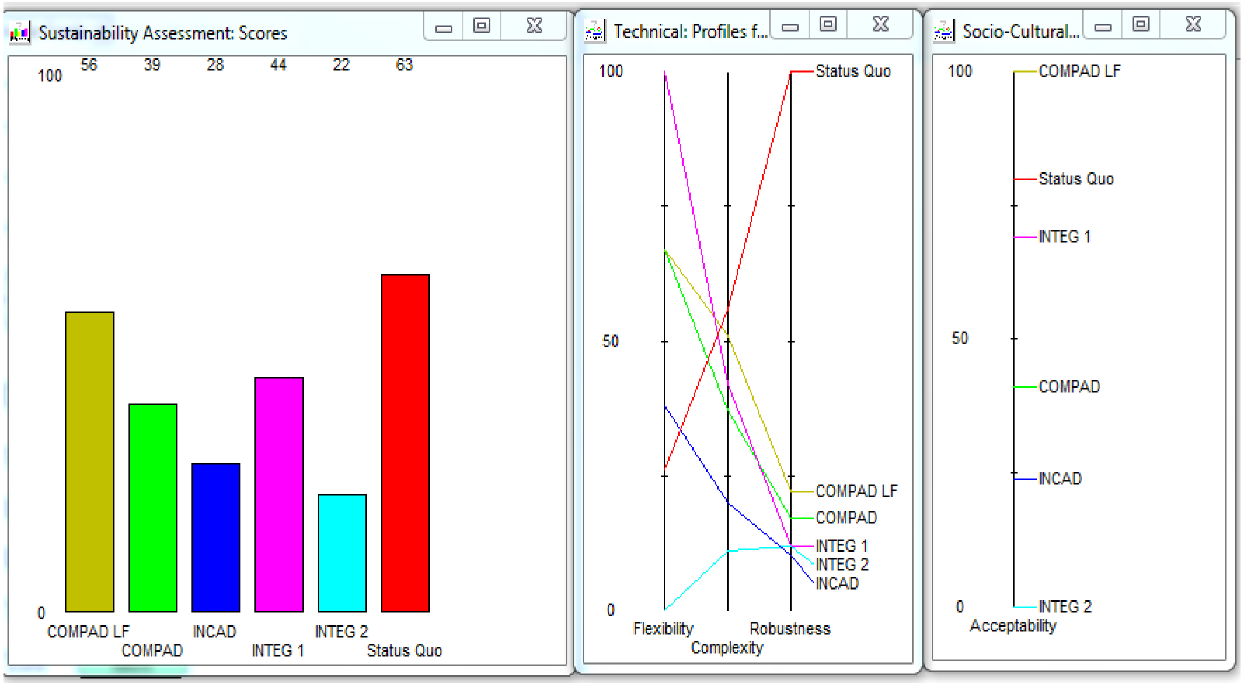

Figure 11-12: Screenshots showing overall sustainability performance of system alternatives with reference to Scenario 2
Source: V.I.S.A Software

Although the **Status Quo** alternative still performed better than other scenarios, the overall sustainability value had decreased by one point as compared to the base case scenario. Moreover, the **COMPAD LF** alternative was only 7 points below the **Status Quo** alternative, registering a sustainability value of 56. Meanwhile, **INTEG 1** alternatives performed better than the **COMPAD** alternative and registered a sustainability value of 44 while the **COMPAD** alternative maintained a value of 39. The **INTEG 2** alternative sustainability results decreased by 4 points in scenario 1 as compared to the base case scenario and the alternative still maintained the last position in the performance trend. In this scenario, only the **Status Quo** and **COMPAD LF** alternatives registered sustainability values above 50 while the **INTEG 1** alternative registered a sustainability value of 44.

Reference to the profiles for the technical and socio-cultural aspects showed variable trends of performance with reference to individual indicators. Noteworthy was that when the technical the aspects were considered, the better performance of the **COMPAD LF** alternative in comparison to other integrated sanitation system alternatives was influenced by high level of system *flexibility,* which was defined by the *adaptability of the sanitation system***.** Given that composting of organic waste at the Mukono Municipal landfill was considered, the potential for further upgrade of the system existed, especially at **UCU**.

Thus, the system was considered to be highly adaptable in comparison to other integrated sanitation system alternatives. While with reference to the socio-cultural aspect, the **COMPAD LF** alternative registered the highest results in comparison to other system alternatives as shown in Figure 11-12.

Sensitivity Analysis for Scenario 3

Taking into account that elicitation of weight values for the indicators was based on input from lecturers, technical staff at **UCU,** interest groups and experts, there were notable variations in weights assigned to indicators as would be expected. As such, weights were clustered into base case, lower and higher value categories**.** As already highlighted**, Scenario 3** analysed the influence of weight variation on the sustainability performance of the alternatives. Adjustment of indicator weights using the low aggregated weights showed a performance trend of **Status Quo>COMPAD LF>COMPAD>INTEG 1>INTEG 2>INCAD** as shown in Figure 11-13.

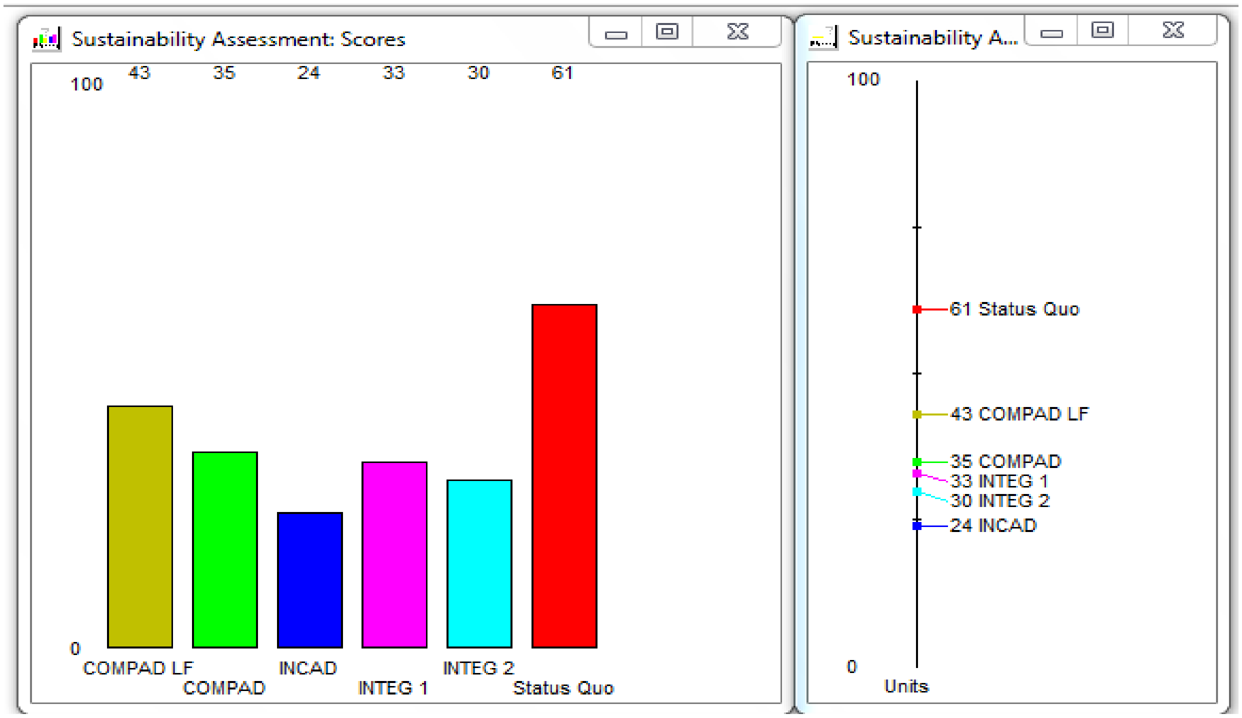

Figure 11-13: Screenshots showing the sustainability performance of system alternatives with reference to low weight values
Source: V.I.S.A Software

In comparison to the base case scenario, it was noted that the overall sustainability values for the **Status Quo**, **COMPAD LF, COMPAD and INCAD** alternatives decreased by at least 3 points while the sustainability value for the **INTEG 1** and **INTEG 2** alternatives increased by at least 2 points when Scenario 3 conditions were considered. Similar to the base case scenario, all sanitation system alternatives except the **Status Quo** alternative registered sustainability values below 50. Also, the trend of performance showed that the **INTEG 2** alternative performed slightly better than the **INCAD** alternative by up to 6 points.

Thus, the trend of performance changed from **Status Quo>COMPAD LF>COMPAD>INTEG 1>INCAD>INTEG 2** in the base case scenario to **Status Quo>COMPAD LF>COMPAD>INTEG 1>INTEG 2>INCAD.** From the performance trends of both scenarios, the **Status Quo, COMPAD LF, COMPAD and INTEG 1** alternatives maintained the same positions and registered sustainability values of at least 30. While **INCAD** and **INTEG 2** alternatives still registered sustainability values less than 30. Moreover, the **COMPAD LF** alternative registered moderate values of 48 and 43 for the base case and Scenario 3 respectively. With reference to the profiles for the respective aspects, similar performance as was the case in the base case scenario was observed. Thus, in case focus was centered on the socio-cultural aspects, then the **INTEG 1** alternative registered the highest value. On the other hand, in case a tradeoff between any of the aspects and technical aspects was considered, then the **Status quo** alternative, which registered the highest value with respect to this aspect could be considered. However, such considerations would have to be based on the objectives of the sanitation system.

In case resource recovery was additionally required of the sanitation system as considered in this research, then the **COMPAD LF** would be preferred to the **Status Quo** alternative. This is because the **COMPAD LF** alternative performed moderately with respect to the technical aspect and additionally considers resource recovery. A tradeoff between other aspects and environmental and natural resources would place the **INTEG 2** alternative as a preferred alternative. Finally, in case the economic aspects were the focus, then the **Status Quo** alternative performed better than other alternatives although in case resource recovery was additionally considered, then the **COMPAD LF** alternative would be preferred. Figure 11-14 shows the sensitivity analysis results reflecting the four aspects for each of the sanitation system alternatives as discussed.

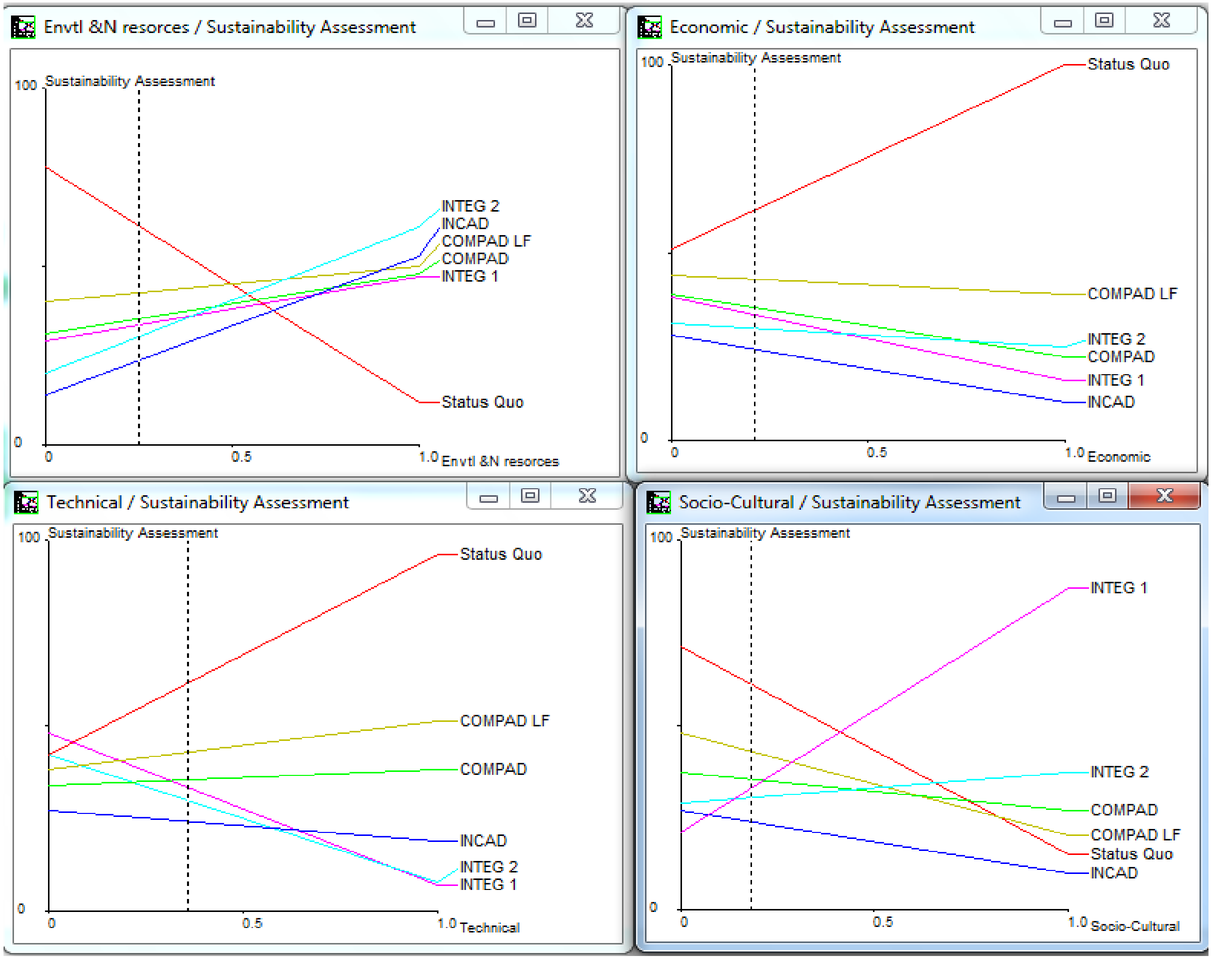

Figure 11-14: Screenshots for the sensitivity analysis for all four aspects sensitivity with reference to Scenario 3
Source: V.I.S.A Software

Where the vertical dotted lines represent the weight settings for the each of the aspects i.e. Environmental and natural resource, economic, technical and socio-cultural.

Adjustment of indicator weights to the high aggregated weights showed a performance trend similar to that when low weight values were used i.e. **Status Quo>COMPAD LF>COMPAD>INTEG 1>INTEG 2>INCAD** as presented in Figure 11-15.

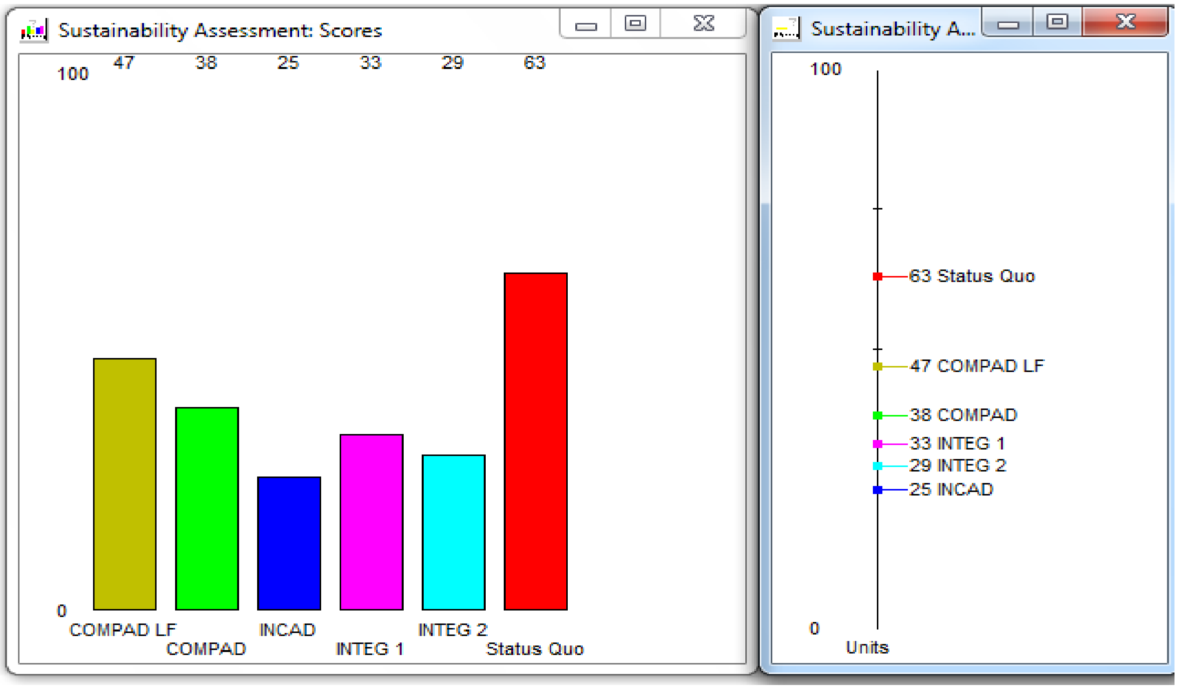

Figure 11-15: Screenshots show overall sustainability scores based on high weight values
Source: V.I.S.A Software

When high weight values were used, increase in sustainability values by at least 2 points was noted for the **Status Quo**, **COMPAD LF**, and **COMPAD** alternatives while the sustainability value of the **INCAD** alternative increased by only 1 point. The sustainability value of the **INTEG 1** alternative remained the same while that of the **INTEG 2** alternative decreased by 1 point. Comparison of the base case Scenario results with the use of high weight values showed a shift in performance trend from **Status Quo** >**COMPAD LF** >**COMPAD** >**INTEG 1** >**INCAD** >**INTEG 2** to **Status Quo>COMPAD LF>COMPAD>INTEG 1>INTEG 2>INCAD.** Variation in positions within the performance trend was mainly noted for the **INTEG 2** and **INCAD** alternatives while all the other four alternatives maintained their positions with respect to the base case Scenario and Scenario 3 when high weight values were considered**.**

Noteworthy was that for the base case, Scenario 1 and Scenario 3, the **Status Quo, COMPAD LF** and **COMPAD** alternatives maintained the first three positions. While in Scenario 2, the **INTEG 1** alternative attained the 3rd position on while the **Status Quo** and **COMPAD LF** maintained positions 1 and 2 respectively. Moreover, for all scenarios considered, the **Status Quo** alternative registered a sustainability result more than 50 while the sustainability results for the **COMPAD LF** alternative varied between 43-56. Meanwhile, the sustainability results for the **COMPAD** alternative varied between 35-46 in all three scenarios considered.

The performance of the **Status Quo** and **COMPAD LF** alternatives with reference to all scenarios resulted in overall sustainability values above or close to the 50 mark. The results also showed that, the **COMPAD** alternative registered sustainability values in the range of 35-46 while the **INTEG 1** alternative registered values in the range of 26-44. As such, to avoid neglecting potentially viable alternatives based on overall sustainability results, the **COMPAD** and **INTEG 1** alternatives were additionally suggested as key alternatives from which decision makers could choose. Taking into consideration that the *means objectives* of this **MCDA** , which included; ensuring improved sanitation and resource recovery, ranking of alternatives for selection by decision makers would consider **COMPAD LF, COMPAD and INTEG 1** in that order. The **Status Quo** alternative was not considered based on the fact that resource recovery was not additionally achieved from the system alternative despite its good performance.

The **INCAD** and **INTEG 2** alternatives registered low sustainability results in the base case Scenario as well as Scenarios 2 and 3. Nevertheless, incase specific tradeoffs of sustainability aspects were taken into consideration, then **INTEG 2** and **INCAD** alternatives could still be opted for. In case the least *environmental burden* and highest *resource recovery* were influencing factors for sanitation system choice, then the **INCAD** and **INTEG 2** alternatives respectively would be preferred. Alternatively, in case socio-cultural aspects were considered the deciding factor for selection of the sanitation system, then the **INTEG 1** alternative would be preferred. While the **COMPAD LF** alternative would be preferred in case technical and economic aspects respectively were considered to influence the final decision regarding system selection. Irrespective of the Scenarios and conditions considered, the results from the **MCDA** indicated that the **COMPAD LF** and **COMPAD** alternatives performed moderately well and could be considered most reliable alternatives.

In general, the sustainability assessment for sanitation system alternatives proposed for **UCU** highlights key aspects to consider when carrying out similar assessments. Prior to carrying out the assessment, a clear definition of the sanitation system purpose or objectives is necessary since this will influence the aspects, criteria and even indicators considered for the assessment. For instance, in considering an integrated sanitation system approach for hospitals, reducing the public health impacts may be given more priority than resource recovery from organic waste management. As such, clear definition of system objectives would in turn influence the criteria and indicators considered. Moreover, the fact that sustainability aspects or pillars are interdependent is an additional reason to ensure that proper definition of the system objectives is carried out at the preliminary stage of the sustainability assessment.

A participatory approach is adopted in carrying out the sustainability assessment using multi-criteria decision analysis. To obtain useful results from the process, selection of participants and continually communicating relevant information becomes a crucial factor. Moreover, by considering a participatory approach, transparency in the decision making process is promoted.

Noteworthy is that often the case participants with various professional backgrounds may be involved in the sustainability assessment, this implies that a level of subjectivity can be expected with regards to the information obtained i.e. scores, weights. As such, in addition to carrying out sensitivity analyses, having an overview of expectations from the assessment may offer the necessary guidance to the whole process. This also infers that irrespective of the domains or entities for which the integrated sanitation system approach is considered i.e. communities, cities or towns, a person(s) with experience on how to carry out the sustainability assessment is crucial for the team involved in the entire planning and implementation process.

Once the results from the sustainability assessment are obtained, appreciation of the various tradeoffs should be considered since this will eventually sanction a comprehensive decision making process. Moreover, by appreciating the various tradeoffs, the context specific aspects of the sanitation system eventually selected can be further emphasised. Given that sustainability assessment of integrated sanitation system alternatives can also enable ranking of alternatives, the rigorous process can be slightly modified, allowing for further consideration of similar system alternatives. This would be particularly feasible in scenarios where similar case study areas are considered. For instance, in case **UCU** considers installing integrated sanitation systems at all of her campuses located in different districts within the country and these campuses have similar conditions, then slight modifications can be made to incorporate any changes and similar system alternatives could be considered and assessed. This would reduce the time required to carry out assessments.

In conclusion, this Chapter discusses the sustainability assessment of the sanitation system alternatives proposed for **UCU** using multi-criteria decision analysis. A combination of methods which included the use of findings from the feasibility assessments and reference to the Helmholtz integrative concept informed the participatory multi criteria decision analysis carried out. The outcomes from the phases of this research i.e. the initiation phase, feasibility and sustainability phases inform the development of a planning framework for the integrated sanitation system approach discussed in Chapter 12.

12 Development of a Planning Framework for the Integrated Sanitation System Approach

Chapter 12 *begins with an overview discussion of the feasibility and sustainability assessment results for the sanitation system alternatives proposed for* ***UCU****. Thereafter a planning framework for the integrated sanitation system approach is proposed based on the findings from the different phases of the research.*

12.1 Implication of Feasibility and Sustainability Assessment Results

The feasibility and sustainability assessments for the sanitation system alternatives proposed for **UCU** were carried out and discussed in Chapters 7 to11 of this dissertation. With reference to the research objectives 1 and 2, understanding of the implications of the assessment results was necessary. The research objectives set out to;

4. Explore the technical, environmental, socio-cultural and economic feasibility of an integrated sanitation system for urban areas in Uganda and considered Uganda Christian University (**UCU**) as a case study.
5. Assess the sustainability of an integrated sanitation system for urban areas in Uganda.

Therefore, a summary of the feasibility and sustainability assessment results is discussed in Sections12.1 and 12.3.

12.2 Summary of Feasibility Assessment Results for UCU

In this research, a holistic approach to feasibility assessment was considered. Hence, technical, environmental, economic and socio-cultural feasibility assessments were carried out for the six sanitation system alternatives proposed for **UCU**. To fully visualise the results from the feasibility assessments, a summary of the performance of sanitation system alternatives with respect to the four aspects mentioned was represented based on a scale of 1-6. The sanitation system alternative that registered the best performance with respect to an aspect was ranked 1 while the alternative that registered the least performance was ranked 6. Table 12-1 gives an overview of the sanitation systems performance with respect to feasibility assessment findings.

Table 12-1: Ranking of Sanitation System Alternatives for UCU with Reference to Feasibility Assessments

Aspects	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Environmental	6	3	2	5	4	1
Economic	3	5	1	6	4	2
Socio-Cultural	1	3	3	2	5	5
Technical	1	3	2	4	5	5
Total	11	14	8	17	18	13

Source: Author

Taking into consideration that the sanitation system alternative with the least value would represent the most feasible, a summation of rank values for each alternative with respect to the four aspects showed that the **COMPAD LF** alternative registered the least total value of 8. This was then followed by the **Status Quo** with a value of 11, **INTEG 2** with 13, **COMPAD** with 14, **INCAD** with 17 and finally the **INTEG 1** alternative registered the highest overall value of 18. Moreover, from ranking summarised in Table 12-1, no sanitation system alternative registered the least rank with regards to all four aspects considered. Even though selection of sanitation system alternatives could be considered by combination of feasibility assessment results for selected aspects, carrying out a sustainability assessment would further reflect the interdependency of aspects, giving guidance to a more comprehensive decision making process.

12.3 Summary of Sustainability Assessment Results for UCU

Sustainability assessments give a complete view of all aspects while promoting transparency and including holistic considerations reflected by the interdependency of aspects (OECD 2008). Sustainability assessment of integrated sanitation system alternatives is a crucial component given that the approach is based on the *Bellagio principles of sustainability* as already discussed in Chapter 2 of this dissertation. Through combined management of organic waste streams, the integrated sanitation system approach considers wastewater and other organic waste streams as resources rather than as “nuisance”. Moreover, incorporation of a participatory approach can be traced through stakeholder involvement in the various phases of planning the integrated sanitation system approach as discussed in previous Chapters of this dissertation. Furthermore, the integrated sanitation system approach suggested in this research focuses on peri-urban and urban areas in Uganda, with a bias towards community, town and city sanitation systems.

The sustainability assessment of the sanitation system alternatives proposed for **UCU** was carried out using **MCDA**. Similar to the feasibility assessments, an overall ranking of the system alternatives reflecting their respective sustainability performance with reference to various Scenarios considered was carried out. A ranking scale of 1-6 was considered with 1 representing the alternative with best performance with respect to the Scenario considered while the alternative that registered the least performance was ranked 6. The scenarios considered included;

Base case scenario; where the scores and weights assigned by experts, lecturers and technical staff from **UCU** as well as interest groups were used as bench mark values. The background of the base case values is that after receiving score and weight values from lecturers, technical staff and experts, the values which were quite variable were separated in to base case, low and high(refer to Chapter 11).

Scenario 1; represented the sensitivity analysis results based on variation of acceptability scores. Here the findings from the **UCU** stakeholder survey for sanitation system acceptability were used in the sustainability assessment as discussed in Chapter 11.

Scenario 2; represented the sensitivity analysis results based on lower value scores assigned to indicators under the technical and socio-cultural aspects.

Scenario 3; represented sensitivity analysis results based on low weight scores for the indicators with reference to base case.

Scenario 4; represented the sensitivity analysis based on high weight scores for the indicators with reference to base case, which were assigned by lecturers, technical staff at **UCU** and experts as discussed in Chapter 11. Table 12-2 summarises the ranking of the sanitation system alternatives with reference to sustainability performance.

Table 12-2: Ranking of Sustainability Assessment for UCU Sanitation System Alternatives

Scenarios Considered	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Base case scenario	1	3	2	5	4	6
Scenario 1	1	3	2	5	4	5
Scenario 2	1	4	2	5	3	6
Scenario 3	1	3	2	6	4	5
Scenario 4	1	3	2	6	4	5
Total	5	16	10	37	19	37

Source: Author

With reference to the ranking scale defined, the sanitation system alternative with the least overall value would represent the most sustainable. The summation of rank values for each alternative with respect to the five Scenarios considered showed that the **Status Quo** registered the least value followed by **COMPAD LF** with 10, **COMPAD** with 16, **INTEG 1** with 19 while **INCAD** and **INTEG 2** shared a value of 37 as shown in Table 12-2. Although the **Status Quo** alternative registered the least overall value, the system alternative does not necessarily consider resource recovery. As such, when resource recovery is additionally considered, then **COMPAD LF, COMPAD** and **INTEG 1** alternatives can be also considered. This was further justified by the fact that when trade-offs between aspects were considered, the **COMPAD LF** alternative was the most selected alternative while **COMPAD** and **INTEG 1** also lay within the efficient frontier.

Besides, the **COMPAD** and **INTEG 1** alternatives were also commonly positioned within the linearity trap (refer to Chapter 11). Reference to feasibility and sustainability assessment results summarised in Table 12-1 and Table 12-2 highlight the good performance of the **COMPAD LF** alternative. While with reference to other sanitation system alternatives, variable performance was registered when both feasibility and sustainability assessments were taken into consideration. The variable performance of other system alternatives further highlights the aspects of subjectivity often expected in assessments and this could also be influenced by assumptions made, in addition to variable points of view, especially when a participatory approach is considered.

Nevertheless, the fact that the results for both feasibility and sustainability assessment indicated good performance by the **COMPAD LF** was quite significant. The overall implications of these results are that integrated sanitation systems suggested in this research were both feasible and sustainable. Hence, objectives 1 and 2 of this research were answered for the case study chosen. Moreover, even though the sanitation system alternatives were proposed for **UCU**, the designs for the system alternatives could still be applied in various locations bearing similar or related conditions and requirements. Naturally, necessary modifications to the system designs would be taken into account to reflect the different local contexts in case integrated sanitation system approach is considered for housing estates, hospitals, peri-urban areas, towns and cities. Inclusion of local context requirements would allow for the design of optimal sanitation system solutions to suit specific conditions (Lüthi et al. 2009; Lüthi et al. 2011b; Andersson et al. 2016a).

Having initially identified entry points for integrated sanitation systems in urban areas of Uganda, reference is made to the findings from the various phases of this research to inform the development of a planning framework. To achieve this task, an understanding of basic criteria considerations for planning integrated sanitation systems is necessary.

12.4 Basic Criteria for Consideration of Integrated Sanitation Systems

Although there are various specific criteria considered when planning and implementing sanitation systems or intervention, most of these criteria fall under two broad criteria which were also considered for the integrated sanitation systems. The criteria include; understanding and analysing the existing context, then identifying entry points for action (Lüthi et al. 2011b; EAWAG-SANDEC 2005).

12.4.1 Understanding and Analysing the Existing Context

Within this broad criterion, a large number and variety of contextual factors exist and these are spread through different sectors such as water supply, health regulation and waste management. Moreover, consideration of domains is crucial in understanding context and these domains include; *households, neighborhoods or community, city and external city* areas. The variability in contexts and domains implies that conflicting demands or conditions between domains or contextual factors are bound to exist (Lüthi et al. 2011b; Andersson et al. 2016a).

Lüthi et al. (2011a) further suggest that since sanitation interventions may require the introduction of novel techniques in an area, it is crucial that consideration of all contextual factors is taken into account. Contextual factors ranging from operational and financial sustainability to human capacity and management arrangements should be considered. Worthy of mention is that often the case these contextual factors overlap each other therefore, related assessments could be simplified by grouping the related factors. Moreover, during such assessments, the contextual factors could be grouped as physical developmental and technological factors of the built environment or as social and institutional factors.

When considering the integrated sanitation systems for **UCU,** understanding the local context was crucial. **UCU** as an entire entity was taken in to consideration and the neighbouring environment was included in the local context. Focus was drawn to organic waste management within the University and measures in place for management of the various organic waste streams were appreciated. Thus, a *neighborhood or community* domain was mainly considered and examination of various contexts in relation to **UCU** was carried out. A combination of detailed assessments, stakeholder input and identification of interest and demand for sanitation improvement informed the design of integrated sanitation system alternatives, which incorporated novel techniques such as briquetting of digestate and incineration of sewage sludge among others. Thus, all contextual factors related to technologies suggested in the system designs were taken into account. These contextual factors, which can be variably grouped are further discussed.

12.4.1.1 Analysing the Physical and Technological Perspective

At this stage, categorisation of settlement types and appreciation of land use would be pertinent to informing a planning framework and later supporting decision-making processes. Thus, proper delineation of boundaries of the settlement types within the urban area would be important. Reference to land use, physical settlement characteristics and a rough assessment of the socio-economic status would also be crucial. In general, the baseline studies of the area often avail necessary information regarding services in the area such as water, sanitation management, energy, existing infrastructure, socio-economic aspects among others. Through carrying out these baseline studies, area mapping can be accomplished exposing the sanitation coverage practices and available infrastructure. Furthermore, identification of areas under stress i.e. areas not sufficiently served by environmental sanitation services can be carried out (Lüthi et al. 2011b; Luethi 2012). From the gap assessment, areas for priority attention can then be easily identified and incorporation of the qualitative issues reflected by social and institutional factors carried out.

With reference to **UCU**, clear delineation of the University boundaries taking into consideration the land use within the campus and neighbouring areas was carried out. Based on the University`s location within Mukono Municipality, the neighbouring land use consisted of variable small and medium scale businesses as well as residential establishments. Moreover, an in-depth understanding of various infrastructure, waste, water and energy management within the University was carried out. Generally, the detailed assessment also resulted in understanding the socio-economic and environmental aspects within **UCU** and its neighborhood. Information on waste management measures i.e. landfilling and composting of organic waste applied by the Mukono Municipality was obtained. Reports from the University and government entities, surveys and informant interviews were some of the modes through which information was obtained. The outcome of this stage enabled a gap assessment which basically indicated that **UCU** experiences a challenge in managing sewage sludge from its **WWTP**.

The University is also still highly dependent on firewood for cooking and is interested in changing this trend by utilising cleaner energy sources such as biogas. Moreover, the 6 year strategic plan (2012-2018) of the University already proposes generation of biogas from organic materials such as sewage sludge. The assessment also identified that Mukono Municipality does not have a centralised **WWTP** or faecal sludge treatment plant. Once gaps have been identified with reference to physical and technological aspects, inclusion of the social and institutional aspects is also necessary to reflect all contexts. Although consideration of both context groups may often be carried out in concurrently, discussions are handled separately for clarity.

12.4.1.2 Analysis of Existing Social and Institutional Context.

The systematic assessment of social and institutional factors that may affect the uptake and/or sustainability of the sanitation intervention may involve there main steps;

- Identification of key actors in each respective domain considered and assessment of their interests, motivations and incentives.
- Understanding the external factors driving decisions in each domain.
- Identification and assessment of capacities in each domain for implementation and long-term management.

Given that a broad range of actors may be involved in the integrated sanitation system value chain i.e. planners, government officials, non-governmental organisations, research institutions among other, clearly identifying these actors and defining their roles and interests is crucial (Lüthi et al. 2011b; Luethi 2012; Andersson et al. 2016a). Clear understanding of actor dynamics would allow for compromises to be made where necessary and this would limit conflicts or possible rejection of sanitation interventions in the long run. Furthermore, conducive multi actor environments /involvement would imply that issues related to fragmentation of environmental services such as improper allocation of funds or mismanagement and conflicts between organisations are avoided (EAWAG-SANDEC 2005; WaterAid 2011). Consideration of the social and institutional factors should also take into account for the different domains.

Analysis of the social and institutional context with reference to **UCU** as a case study area included identification of actors, appreciation of their roles and interests. Through consultations, key informant interviews and surveys, students, teaching and non-teaching staff at **UCU** as well as experts in various fields of sanitation, energy and biogas were consulted. Other actors consulted included government officials, officials from NGO`s and local farmers to mention but a few.

A list of persons consulted is included in Appendix 2. Through interaction with the various actor groups, related to possible incentives and development trends in related areas, including the available institutional framework was obtained. Furthermore, insight on potential drivers for decisions related to the integrated sanitation system approach and foresight on potential conflict areas was obtained. The entry points for integrated sanitation systems were already identified as peri-urban and urban areas in Uganda.

Focus was drawn to community, town and city domains thus, non-residential buildings or settlements, planned development areas, peri-urban and inner city areas were considered. As already mentioned in Chapter 3 of this dissertation, examples of entities considered within these main groups included; institutions of learning, hospitals, housing estates, towns and cities among others. With reference to the identified potential of integrated sanitation systems in urban areas in Uganda, guidance for planning and implementation such systems was deemed necessary. Thus, based on review of existing environmental sanitation planning tools and experiences obtained from accomplishing the various phases of this research using **UCU** as a case study. Sections 12.5 of this Chapter discusses the development of a planning framework suggested for integrated sanitation systems.

12.5 Urban Sanitation Planning and Implementation Frameworks

A review of most of the urban sanitation tools considered in this section was already carried out in Chapter 2 however, this Section focuses on the steps considered in these planning tools.

12.5.1 Participatory Hygiene and Sanitation Transformation (PHAST)

The **PHAST** sanitation approach focuses on empowering communities to improve hygiene behaviors, prevent diarrhoeal disease, and encourage community management of water and sanitation facilities. The planning framework adapts a participatory approach to community learning and planning that follows seven steps i.e. (i) problem identification, (ii) problem analysis, (iii) planning for solutions, (iv) selecting options, (v) planning for new facilities and behavior change, (vi) planning for monitoring and evaluation, and (vii) participatory evaluation (Sawyer et al. 1998; UNICEF 2008; Kvanström et al. 2008).

12.5.2 Household Centered Environmental Sanitation (HCES)

Developed by **EAWAG**, the planning framework for **HCES** recognises the importance of management zones within the urban environment. Households and neighborhood domains are at the core of the planning, implementation and operation processes regarding urban environmental sanitation services**.** The **HCES** framework consists of a ten-step process summarised in Figure 12-1.

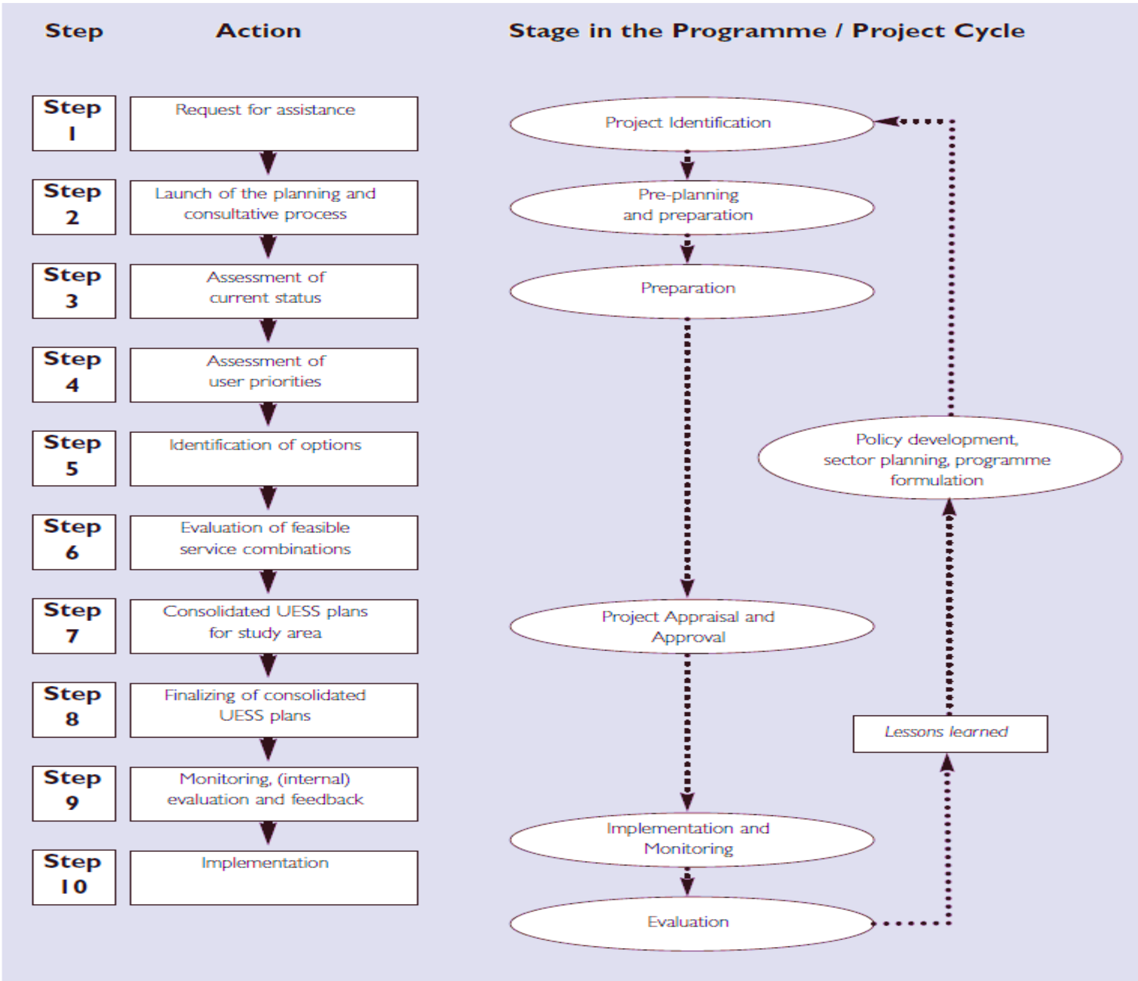

Figure 12-1: The 10 step process for HCES
Source: (EAWAG-SANDEC 2005)

12.5.3 Community Led Urban Environmental Sanitation (CLUES)

This planning framework focuses on community level involvement in urban sanitation planning, taking into consideration the whole value chain. **CLUES** consists of only 7 planning steps i.e. (1)process ignition and demand creation, (2) launching of the planning process, (3)detailed assessment of current situation, (4)prioritisation of community problems, (5)identification of service options, (6)development of action plan and (7)implementation (Lüthi et al. 2011a).

12.5.4 Sanitation 21

Sanitation 21 concentrates on sanitation planning for urban and peri-urban areas and promotes an analysis of the objectives of a sanitation system. The planning consists of five stages which include; (1) building institutional commitment and partnership for planning, (2) understanding the existing context and defining priorities (3) developing systems for sanitation improvement, (4) developing models for service delivery and (5) preparing for implementation (Kvanström et al. 2008; Parkinson et al. 2014; IWA 2006).

12.5.5 Network for Sustainable Sanitation Approaches in Africa (NETSSAF)

NETSSAF was developed to support decision making with reference to sustainable sanitation for large scale implementation in West Africa. The planning approach also factored in identification of the technical and non-technical requirements for the large-scale implementation of sustainable sanitation systems for typical rural and peri-urban settlements (Kvanström et al. 2008). The **NETSSAF** planning framework which incorporates a participatory approach includes 8 steps i.e.

- Project start-up and launch of the planning process,
- Creation of a demand for improved sanitation,
- Assessment of existing sanitary situation and user priorities,
- Construction of demonstration units,
- Identification of feasible sanitation concepts and service systems,
- Consolidation and finalization of implementation plans for sustainable sanitation,
- Implementation
- Participatory monitoring and evaluation

12.5.6 Multi-Criteria Decision Support Systems (MCDSS)

By the mere fact that urban sanitation consists of a broad scope, multiple actors and criteria are often considered, especially during sustainability assessments. Such assessments inform the planning and implementation process thus, a brief discussion of the **MCDSS** framework is incorporated in this section. Decision Support Systems (**DSS**) are derived from the theory of decision analysis and are designed to help decision makers resolve issues of trade-offs through the synthesis of information. When identification of trade-offs between the variety of information is required, **MCDSS** are used. Usually, the information considered to guide decision making may be presented as quantitative and or qualitative data which is common with reference to sanitation.

Merited for increasing transparency, structuring complex problems, boosting stakeholder participation and ensuring optimisation, **MCDSS** have been used to guide decision-making related to sanitation as discussed in Chapter 11 of this dissertation. (Belton and Stewart 2002; Kvanström et al. 2008). Generally, **MCDSS** consist of at least 6 steps, which include; (1)identification of problems, 2) formulation of objectives, criteria and indicators, (3)identification/formation of alternatives, (4)description of performance for each alternative, (5)weighting and evaluating scores of criteria for each alternative, (6)examining results and conducting a sensitivity analysis

12.6 Development of an Integrated Sanitation System Planning Framework

Except for **MCDSS,** the urban planning frameworks briefly discussed in Section12.5 take into consideration aspects of environmental sanitation. However, each framework fully tackles variable aspects and domains i.e. hygiene as well as rural and urban settlements where households, communities, or city domains are considered. As pointed out in Chapter 2, these planning frameworks place emphasis on offering sanitation services in different domains.

Given that urban areas often consist of variable domain with different sanitation needs, providing sanitation services may invariably require a mixture of sanitation systems appropriate for different domain. Therefore, the existence of a sanitation approach which holistically considers environmental services for urban areas while incorporating the different domains i.e. community and city/town could be attractive. The integrated sanitation system approach proposed for urban and peri -urban areas considers mainly the neighborhood/community and town or city domains. Furthermore, focus is drawn on management of organic waste streams and effluent reuse instead of the broad generic guide for multiple components of environmental sanitation cited in the planning frameworks discussed.

Moreover, the existing planning frameworks are considered "silent" with regards to assessment of sanitation alternatives. **Sanitation 21** and **CLUES** promote a more generic analysis on several sanitation systems while **HCES** offers a list of criteria for technology selection and **PHAST** depends on participant feedback for assessment of sanitation options. In all these tools, no reference is made to the meaning of a sustainable technology in a particular context. Besides, a procedure for sanitation technology sustainability assessment does not exist, yet most of the approaches are based on the *Bellagio sustainability principles*. As such, the planning and implementation framework for the integrated sanitation system approach attempts to fill the gaps identified i.e. incorporate sustainability assessment within the tool.

The planning framework for the integrated sanitation systems approach adopts certain of steps from existing frameworks taking into consideration experiences attained from **UCU** as case study. The proposed planning framework for integrated sanitation systems emphasises a participatory approach while incorporating a holistic feasibility assessment approach for the sanitation alternatives considered. In addition, sustainability assessment of alternatives and a capacity building component, which is meant to enable informed decision making is considered. Through inclusion of demonstration units of selected sanitation systems, awareness is raised while enhancing capacity building in the long run The integrated sanitation systems planning and implementation framework suggested combines experience obtained from **UCU** as a case study and the following frameworks or methods; **CLUES, Sanitation 21, NETSSAF, MCDSS.** Table 12-3 gives a comparative overview of the planning frameworks discussed and the suggested steps for planning framework of the integrated sanitation system approach.

Table 12-3: Comparison of the Urban Sanitation Planning Frameworks and Relevant Methods

	PHAST [a]	HCES [b]	CLUES [c]	Sanitation 21 [d]	MCDSS [e]	NETSSAF [f]	Integrated Sanitation System Approach
Context assessment	Problem Identification	Request for Assistance	Process Ignition and Demand Creation	Build Institutional Commitment and Partnership for Planning	Definition of Problem, Goals and Objectives	Project start-up and Launch of the Planning Process	Process Initiation and Demand Creation
	Problem Analysis	Launch of Planning Process	Launch of the Planning Process	Understand the Existing Context and Define Priorities	Definition of Criteria	Creation of a Demand for Improved Sanitation	Launch of the Planning Process
		Assessment of current Status	Detailed Assessment of the Current Situation	Develop Systems for Sanitation Improvement		Assessment of existing Sanitary Situation and User Priorities	Detailed Assessment of the Current Situation and Prioritisation of Problems
		Assessment of user priorities	Prioritisation of the Community Problems and Validation				
Technical options	Planning for Solutions	Identification of Options	Identification of Service Options	Develop Models for Service Delivery	Definition of Alternatives	Construction of Demonstration Units	Identification of Alternatives and Holistic Feasibility Assessments
Feasibility	Selecting Options	Evaluation of Feasible Service Combinations	Development of an Action Plan		Definition of preferences	Identification of Feasible Sanitation Concepts and Service Systems	Sustainability Assessment of Sanitation Alternatives

	Planning for New Facilities and Behavior Change					Consolidation and Finalisation of Sustainable Sanitation Plans	
	Planning for Monitoring and Evaluation						Application of Demonstration Units for Selected Alternatives
Implementation	Participatory Evaluation	Consolidate Plans	Implementation of the Action Plan	Prepare for implementation	Decision Making	Implementation	Implementation
		Finalise Plans				Participatory Monitoring and Evaluation	Evaluation and Monitoring
		Monitoring, Evaluation and Feedback					
		Implementation					

Sources: a-(Sawyer et al. 1998), b-(EAWAG-SANDEC 2005), c-(Lüthi et al. 2011a), d-(Parkinson et al. 2014), e-(Belton, and Stewart 2002), f-(Kvanström et al. 2008)

12.7 Integrated Sanitation System Planning Framework-Model

To enable planning and possible implementation of integrated sanitation systems for urban and peri-urban areas in Uganda, this research proposes a framework. The proposed steps for the planning and implementation framework are based on certain existing urban sanitation frameworks briefly described in Section12.5. In addition, experiences from exploring integrated sanitation systems for **UCU** informed the development of the planning framework model. The integrated sanitation system planning framework model consists of 8 steps as described in the following sections.

12.7.1 Process Initiation and Demand Creation

The planning process is initiated consists of three sub steps, which include; *kick off, initial meeting and stakeholder identification.* During the *kick off stage,* sanitation and hygiene problems in the target area are triggered by the community or responsible entity such as NGO`s, local authority/determined process leader etc. The motivation to improve their immediate environments with particular focus on organic waste management stirs up the *kickoff* stage while creating demand improvement in environmental sanitation services. Furthermore, during this step "champions" for the project can be identified. Champions include individuals, groups, political leaders or organisations that have the ability to influence change because of the respect accorded to them with reference to a project or community members. With reference to the domains for which the integrated sanitation systems are proposed i.e. community and town or city domains, the *kick off* stage may vary or be skipped(Lüthi et al. 2011a; Parkinson et al. 2014). For instance, in inner city areas, awareness about integrated sanitation systems may have already been raised as such, the *kick off* stage maybe skipped.

Once the process has been started, *initial meetings* which build on the momentum already created should be held. These meeting should aim to further mobilise and inform the different responsible entities/parties while additionally identifying their main concerns. Both *initiation* and *initial* meeting stages already give preliminary information regarding potential stakeholder involvement. As such, the *stakeholder identification* step then caters for identification of other stakeholders while refining the stakeholder list and obtaining stakeholder concerns i.e. stakeholder analysis is carried out. Moreover, throughout the project *kick off, initial meetings* and *stakeholder identification* steps, any promotional activities can be considered to boost the entire process.

Therefore, through sensitisation, the momentum regarding the sanitation situation is created and a platform for community or stakeholder participation is initiated. Once the initial stakeholder/community meetings have been held, any necessary agreement(s) on action should be formulated and the relevant task force formed. The task force formed should include the identified project champions to further boost implementation of other project phases. The task force formed can then acts as the interface between the potential sanitation system users and other stakeholders (Lüthi et al. 2011a; Parkinson et al. 2014; Kvanström et al. 2008).

Accomplishment of various activities within initiation and demand creation step can be enhanced using tools such as interviews, questionnaires, participatory assessment methods, stakeholder analysis, meetings and workshops.

12.7.2 Launch of the Planning Process

During the launching step all key stakeholders formally meet to develop a common understanding of the environmental sanitation problems pertinent to the designated area and is this proceeded with any necessary documented agreements on how to address the problems identified. An inclusive, well-structured workshop or general meeting can be held to attract the much needed public attention. Moreover, a clear communication about the integrated sanitation system approach as well as a stakeholder assessment and agreement on project boundaries should be carried out. In addition, problem assessment while clearly delineating the necessary planning methodology and agreement on responsibilities to be held by various actors should be discussed during the launching process.

The outcomes of this step could include protocol agreements, agreements on project boundaries and agreements on overall planning methodology and process. Similar tools to those used in the initiation and demand creation step can be used to attain the necessary agreements mentioned (EAWAG-SANDEC 2005; Lüthi et al. 2011a; Kvanström et al. 2008). Noteworthy is that depending on the entity for which an integrated sanitation system approach is being considered for, the launch of planning process could be incorporated in the initiation and demand creation step. For instance, if the integrated sanitation system approach is considered for cities or towns, where key stakeholders may include government authorities and regulatory bodies, launching the planning process may be incorporated within the initiation and demand creation step.

12.7.3 Assessment of Current Situation and Prioritisation of Problems

In this step, a good understanding of the local context taking into consideration the existing physical and socio-economic environment of the designated areas is crucial. As such, compilation of information about the physical and socio-economic environment of the designated area is carried out with the intention of understanding the factors that influence environmental sanitation services. The assessment task can be coordinated by a researcher/institution or organisation that is familiar with the area and understands the complex sectoral issues and service delivery problems. The detailed assessment should include a participatory approach which takes into account elements of environmental sanitation, particularly organic waste management. Moreover, the views or experiences of the community or key entities planning integrated sanitation system for cities should be taken into account (Lüthi et al. 2011a; Parkinson et al. 2014).

To inform the detailed assessment, collection of relevant information about the project area from all available sources is necessary. Besides, a full assessment of the enabling environment should be carried out. The enabling environment should reflect on issues such as sector legislation and regulations, availability of human resources and skill levels, required material, sector finance, health and hygiene levels. In addition, gender roles and security aspects of the areas should be taken into consideration.

The assessment of the current conditions and services in the designated area should be carried out and this should reflect on the existing sanitation facilities and entire sanitation value chain. The assessment can enable mapping of the area to highlight where improvement in environmental sanitation services is required while considering multi-dimensional aspects such as, consumption patterns, income, waste management etc. With reference to the information obtained, possible interlinkages between components and elements of environmental sanitation services can be exposed. The identified interlinkages in environmental sanitation services should also enable further refining of stakeholders involved in the project. The outcome of this step is identification of gaps and prioritisation of the problems within the designated area. Moreover, relevant baseline data is obtained as well as a detailed assessment of the enabling environment and the existing levels of service provision within the area are attained. Finally, a refined stakeholder analysis is also obtained and a detailed assessment report can be generated for the project area (EAWAG-SANDEC 2005; Kvanström et al. 2008; Lüthi et al. 2011b).

Checklists, interviews, questionnaires, participatory assessment methods and status reports are some of the tools that can be used to obtain the necessary information in this step. This step provides the necessary background information for the future planning steps.

12.7.4 Identification of System Alternatives and Feasibility Assessments

Based on the outcome from step 3 as well as input from various stakeholders including environmental sanitation experts, a team composed of engineers, planners and other experts then identifies or proposes sanitation system alternatives, which are considered feasible for the intervention area. The sanitation system alternatives or improvement service options can be studied in greater detail to appreciate their feasibility and enable further screening (Lüthi et al. 2011a; Andersson et al. 2016a; Parkinson et al. 2014). As such, a holistic feasibility assessment approach can be considered at this stage, where assessments not limited to technical, economic, environmental and socio-cultural associated with the sanitation system alternatives aspects are carried out. These assessments can be variably defined to suit the context for which the integrated sanitation systems are being considered. Thus, appreciation of material and skill requirements for system construction, requirements for operation and maintenance are taken into consideration. Also, estimation of potential budgets, sources of funding and associated benefits from the sanitation system in addition to system acceptability are considered.

Therefore, the feasibility assessments for the sanitation system alternatives can be carried using various tools ranging from life cycle assessments, cost benefit analysis, system functionality assessments to socio-cultural assessments. A summary report incorporating the relevant feasibility assessments can then be generated by experts/researchers or responsible organisations and discussed or presented to decision makers for further consultation. Other tools that can be used to enhance activities in this step include sanitation system manuals, costing tools and surveys. The outcome of this stage includes sanitation system alternatives with the respective strengths and weaknesses highlighted through the feasibility assessments.

Moreover, a detailed description of the system alternatives, indicating the system technical components and possible linkage to other aspects i.e. technical, environmental, socio-cultural as well as economic aspects are included.

12.7.5 Sustainability Assessment of Alternatives

This step adopts the **MCDA** approach to further enable decision making and selection of a sanitation system based on sustainability assessment. The identification of sustainability criteria and indicators for assessment of the system alternatives is carried out based on a combination of methods. Some of the methods that can be considered include; literature review of relevant sustainability criteria and indicator sets, reference to the Helmholtz integrative concept of sustainable development and the local context in addition to soliciting input from stakeholders. Moreover, reference to the holistic feasibility assessments should also inform the selection of criteria and indicators used for the sustainability assessment of the sanitation system alternatives.

Once the sustainability assessment criteria and indicator sets have been selected, elicitation of indicator and criteria scores and weights is enabled by findings from the holistic feasibility assessments in addition to stakeholder input. After all the criteria and indicator data has been obtained, the sustainability assessment of the sanitation system alternatives can be carried out using a preferred **MCDA** tool. A participatory approach is adopted throughout the **MCDA** process, where stakeholders are consulted to elicit their views on criteria considered in addition to assigning scores and weights to the criteria and indicators. The outcome of this step includes ranking of sanitation system alternatives and, or selection of preferred alternative with reference to the sustainability goals defined.

12.7.6 Application of Demonstration Units

In consultation with key stakeholders or decision makers, demonstration units of the preferred system alternatives can be constructed. Incorporation of demonstration units is meant to allow for collection of additional information, which could contribute to necessary adjustments in system designs prior to final or additional sanitation system implementation(Kvanström et al. 2008). Through stakeholder involvement in this step, the potential sanitation system users, various involved authorities and stakeholder groups have access to information from operational sanitation systems, which then act as reference points. Information obtained from the demonstration units can also be used to boost sanitation system improvement, especially in case up scaling is considered. The acquired experience and information from the demonstration units can eventually help raise awareness regarding the integrated sanitation system approach while building capacity in the long run. Noteworthy is that inclusion of demonstration units may be dependent on the priorities of the entity interested in the integrated sanitation systems. Factors such as availability of financial resources, regulatory and institutional requirements among others may influence the consideration of demonstration units.

12.7.7 Implementation

Once the final choice of the sanitation system and any necessary improvements in system design have been made, then implementation can proceed. Implementation is a process within itself where the final outcome from decision makers, which was informed by sustainability assessment and experiences from the demonstration units is brought to reality. Implementation requires an adaptive and flexible project management approach with continuous feed-back through monitoring and evaluation of the system (Kvanström et al. 2008; Lüthi et al. 2011a). Some of the key activities in this step could include development of detailed construction, operation and monitoring plans. Prior to the implementation of selected sanitation systems, necessary approval of the plans should be obtained from responsible authorities. Furthermore, within this step, procurement and contracting of suitable service providers to implement the various project tasks or phases is pertinent.

Therefore, necessary tools such as bidding documents for construction services, contracts as well as operation and maintenance user manuals enable the implementation process. The outcome from the implementation step includes a final plan which clearly communicates the agreed strategy for financing and implementation of the priority components. Moreover, clear communication of target actions which promote sanitation through advocacy and raising of awareness in addition to a well-developed capacity building strategy should be included in the plan (Parkinson et al. 2014; Lüthi et al. 2011a).

12.7.8 Monitoring and Evaluation

A participatory approach is emphasised throughout the planning process thus, monitoring and evaluation methods are used throughout the project as a feedback system. The feedback system in turn increases consensus amongst the stakeholder groups on appropriateness of goals, objectives and activities. The monitoring process mainly assesses project progress while ensuring that the planning and implementation processes stay on course. Hence, a situation analysis that questions the status, future plans or targets and the way forward can be carried out during monitoring of an integrated sanitation system.

The monitoring and evaluation step provides timely, reliable, and valid information for coordinating and managing the other planning and decision making steps (Kvanström et al. 2008). Although the suggested integrated sanitation system approach framework has been described in a stepwise manner, in reality some of the steps may overlap and others will be iterated as new information is revealed when feedback is obtained. Moreover, the time lapse in accomplishing the various steps may vary, especially since the framework emphasises a participatory approach, which is dependent of input or feedback from various stakeholder groups. Table 12-4 gives a summary of the integrated sanitation system approach planning framework suggested.

Table 12-4: Summary of an Integrated Sanitation System Approach Planning Framework

No	Steps	Activities	Tools	Outcome
1	Process initiation and demand creation	• Kick off • Initial meeting(s) with respective entities, communities or groups • Stakeholder identification	• Initiation and demand creation methods • Interviews, questionnaires • Participatory assessment methods • Organising meetings, events • Stakeholder analysis	• Increased awareness on water, sanitation, hygiene issues • Identification of project champions • Key organic waste management(sewage , faecal sludge, organic solid waste, wastewater etc.) issues identified • Mapping and definition of project boundaries • Formulation of an agreement for action • Formulation of a task force • Preliminary inventory and characterisation of stakeholders
2	Launch of the Planning Process	• Presentation of the situation- an overview • Presentation of the integrated sanitation system approach • Where feasible, a participatory stakeholder assessment should be carried out • Agreement on project boundaries • Assessment of problem by different stakeholders • Approval of planning methods and agreement on responsibilities • Documentation of launching process	• Participatory assessment methods • Meetings • Stakeholder analysis • Presentation tools e.g. power point slides • Problem identification tools e.g. problem tree analysis	• Decision to proceed with planning • Participatory assessment • Definition of project boundaries • Clear definition of problem statements • Approval of planning methodology and agreement on process and responsibilities • Necessary documentation on project launching • Formation of a project coordination committee and necessary task force

3	Assessment of current situation and prioritisation of problems	• Collect and synthesise existing information about the project area • Conduct an assessment of the enabling environment • Conduct an assessment of the current conditions and services in the project area • Refine the stakeholder analysis from previous steps	• Interviews ,questionnaires, checklists • Participatory assessment methods • Stakeholder analysis • Status reports, other available literature(strategic plans, government reports)	• Refined stakeholder analysis • Relevant baseline information • Status assessment report, summarising all main findings.
4	Design of sanitation system alternatives and feasibility assessments	• Design, pre-selection and feasibility assessment/evaluation of sanitation alternatives through expert/researcher or assigned team consultation • Consultation with responsible entity i.e. community, group, etc.	• Meetings • Sanitation system manuals e.g. compendium of sanitation systems and technologies, costing manuals etc. • Assessment checklists, questionnaires • Feasibility assessment tools e.g. life cycle assessment, cost benefit analysis, surveys, material risk assessments, flow analysis among others	• Matrix of pre-selected sanitation systems, including main requirements, strengths and limitations for each system and criteria which influenced the pre- selection • Report/documentation detailing technical, environmental, economic and socio-cultural aspects related to each sanitation system alternative.
5	Sustainability assessment of sanitation alternatives	• Identification of relevant criteria and indicator sets • Elicitation of criteria and indicator score and weight information • Sustainability assessment of alternatives based on criteria and indicator information obtained	• Reports/studies on sustainability assessment of sanitation systems • Helmholtz integrative concept of sustainable development to further enable indicator identification • Meetings with specific stakeholders	• Ranking and, or selection of sanitation system alternatives based on sustainability assessment

			• Questionnaires • Multi criteria decision analysis	
6	Application of demonstration units	• Construction of demonstration units	• Stakeholder meetings • Sanitation system design manuals • Sample operation and maintenance documents • Funding opportunities	• Pilot or demonstration sanitation systems
7	Implementation	• Development of detailed construction operation and monitoring plans based on experiences from demonstration units • Procurement and contracting • Implementation, supervision and commissioning of sanitation system • Inauguration ceremony	• Meetings and workshops • Operation and maintenance documents • Bidding documents for Construction Services • Contracts with respective service providers	• Proposals for implementation of physical works • Implementation monitoring plan • Tender documents and contracts • Construction, installation and operation of Integrated sanitation infrastructure • Execution of operation and monitoring plan, including necessary training • Final project documentation and these could include reports, posters, videos, maps etc. • Publicity from demonstration units and project inauguration
8	Monitoring and Evaluation	• Monitor sanitation system planning and implementation processes • Evaluate sanitation system performance over specified time durations	• Project time schedule/agreement plans • Operation and maintenance documents • Checklists	• Project status reports • Periodic evaluation reports

Sources: Author

Having proposed a planning and implementation framework for the integrated sanitation system approach, an understanding of the enabling environment is crucial to assess and foster favorable conditions. In an ideal scenario, prior identification of the elements of an enabling environment could inform the planning process and this would limit unrealistic expectations or misconceptions regarding the integrated sanitation system approach. However, often the case the critical elements supporting an enabling environment are identified or become evident during the planning process. Six key elements of the enabling environment suggested in **CLUES** planning tool and also highlighted in Chapter 3 of this dissertation of are also considered relevant with regards to the integrated sanitation system approach. These elements are briefly discussed in the following Sections.

12.8 Government Support

Similar to any sanitation approach, support from political players would significantly influence the extent to which the integrated sanitation system approach is supported or hindered even though national policies and strategies for the sanitation sector are also important. Lack of political will has long been cited as one of the challenges met in implementing urban sanitation in Africa (EAWAG-SANDEC 2005; WaterAid 2011). Therefore, to enable integrated sanitation system implementation, clarity on commitment from political leaders within specific jurisdiction such as municipal governments, town councils, relevant ministry representatives would be a necessary precondition.

Moreover, government support can also be reflected by available policies or national frameworks in place. Uganda has national policies for sanitation, water, health and other national plans/strategies although some of the strategies are "silent" on the specificities of urban sanitation. Nevertheless, regulations, standards, and district local government bylaws as well as ordinances relevant to environmental sanitation exist and can be referred to (NEMA 1995; KCCA 1997). In the event that political leaders are not yet on "board" with the proposed integrated sanitation system approach, then it is recommended that a project leader sensitise political leaders to get them involved.

12.9 Legal and Regulatory Framework.

The performance of governments is depicted in detail by laws, regulations, standards and codes within the overall policy framework. The regulations specify how services are to be provided and this gives details on the responsible entity, the delivery standards to be met in addition to the ownership of infrastructure and services. Furthermore, regulations give the necessary procedures for tariff allocation and other cost recovery methods. Therefore, for effective planning and subsequent implementation of the integrated sanitation system approach, designers and system implementers should examine the legal framework within which potential beneficiaries and communities operate. This would enable identification of any constraints and give the necessary guidance on how to address identified challenges (Kvanström et al. 2008; Lüthi et al. 2011a). Experiences from **UCU** as a case study showed that Uganda has relevant regulations in place some of which include; National Environment (Waste Management) Regulations, 1999, National Environment(Air Quality) Regulations-2016, National Sanitation Policy for Uganda, 1997 among others.

There are also local government ordinances which give guidance relevant to environmental sanitation components i.e. the Local Government Act, Kampala City Council Authority-Waste Management Ordinance among others (KCCA 1997; NEMA 1995). Nevertheless, there is need for more specific regulations to give the necessary guidance on other aspects such as, the application of biosolids from sewage/faecal matter to land or use of the biosolids in aquaculture. Moreover, specific regulations to check pollution from incinerators would also be necessary, especially in cases where future application of incinerators on large scale is envisioned.

12.10 Institutional Arrangements

Given that the integrated sanitation system approach strongly emphasises a participatory approach, an understanding of the institutional environment within which the various institutional levels can function effectively is crucial. The institutional frameworks of an integrated sanitation system project encompass communities, NGOs, both the public and private sector. As such, an understanding of the roles, responsibilities, interests and capacities of the different stakeholder groups with reference to provision of organic waste management is fundamental to defining institutional arrangements for the project (Hermans and Taketa 2006; Reed et al. 2009; Cross and Coombes 2014). Thus, a detailed stakeholder analysis could fully inform institutional requirements for the integrated sanitation systems.

Irrespective of the different entities for which the integrated sanitation systems are considered i.e schools/institutions of higher learning, housing estates, towns, cities, common stakeholder groups will be involved. Some of these stakeholder groups include; local authorities, municipalities, NGOs, funding agencies, private service providers, users of byproducts from the sanitation system i.e farmer, landscapers etc. Noteworthy is that stakeholder analysis which is an iterative process can be carried out throughout all steps of planning and implementation, implying that other stakeholders may be included at later stages of the project.

12.11 Capacity and Skills

An essential part of the enabling environment for the implementation of the integrated sanitation system approach is adequate knowledge, skills and capacities in various fields of engineering, sanitation, renewable energy, sociology, management, environment to mention but a few. Moreover, the ability to obtain the necessary skill set and materials for construction, operation and maintenance of the various systems within the implementation area is an added advantage**.** Furthermore, since resource recovery is also a key objective of the integrated sanitation system, a broader system value chain can be expected. Besides, the emphasis on a participatory approach implies that project management, negotiation and problem solving skills as well as stakeholder coordination will be pertinent for successful implementation of integrated sanitation system. In addition, conflict resolution and organisational skills are required since various actors/stakeholders will be involved(Cross and Coombes 2014).

Therefore, identification of institutions and/or agencies that possess such high capacity to conduct the necessary management aspects of proposed projects while additionally availing necessary skills would boost integrated sanitation system implementation.

12.12 Financial Arrangements

For any investment, appreciation of the financial expectations is inevitable. Thus, in case integrated sanitation systems are considered, the cost implications of the systems have to be reflected. The willingness of the different partners or decision makers to contribute financial resources and time to the project planning and implementation should be assessed in the early stages of the project. Such assessments will give additional foresight on the feasibility of an integrated sanitation system project. The ability to obtain financial contributions and investments from various entities such as potential system users, governmental agencies, private sector and donors would boost the implementation of the integrated sanitation system.

Moreover, consideration of all cost related aspects including administrative requirements, material costs, training, social marketing programmes when making cost estimates would give a more comprehensive assessment. Some sources of capital financing for the integrated sanitation system could include; grants, targeted government grants, credits from government initiatives such as, the **Uganda Energy Credit Capitalisation Company** (**UECCC**), which avails financial resources in the form of loans to support renewable energy related projects. In addition, credits in the form of loans can be obtained from banks. Meanwhile, integrated sanitation system projects can also be registered as Clean Development Mechanism (**CDM**) projects, thereby obtaining funding from carbon offsets (CDM 2009).

12.13 Socio-Cultural Aspects.

Consideration of the socio-cultural aspects is crucial, especially when the longevity and sustainability of a sanitation approach is considered. The community or relevant entities/stakeholders should be willingness to participate in a long-term process of planning, implementation and later monitoring of the integrated sanitation system project. Given the scope of the integrated sanitation system approach, changing of habits, mindsets and behaviour of the various actors involved can be expected. Bearing in mind that culture may influence people`s behaviour, habits and attitudes, appreciation of the Socio-Cultural aspects related to integrated sanitation system acceptability from instance becomes extremely important (Andersson et al. 2016a; Warner et al. 2008).

Therefore, by assessing the socio-cultural aspects related to the integrated sanitation system, certain pointers such as receptiveness by the entity or community to new ideas and possibility of behaviour change can be appreciated at an early stage of the project. Also, the availability of local organisations or entities already participating in similar projects and existence of champions to promote the approach would be additional motivate integrated sanitation system implementation.

Furthermore, awareness campaigns and sensitisation could avail the necessary information to influence behaviour change, perception and attitudes related to the integrated sanitation system approach(Lüthi et al. 2011a; Kvanström et al. 2008; Peal et al. 2010). Consequently, taking into consideration the elements of enabling environment discussed, the planning and implementation framework for integrated sanitation system approach can be used as a guiding tool for implementation of the sanitation systems in the identified urban and peri-urban areas in Uganda. The suggested framework was a result of information obtained from all phases of this research which included initiation, feasibility assessment and sustainability assessment phases as highlighted in the conceptual framework. Moreover, reference to existing environmental sanitation planning frameworks additionally informed the development of the planning and implementation framework for the integrated sanitation system approach proposed in this research. The proposed planning framework answers the third research question, which sought to **identify the main steps required in the planning of integrated sanitation systems** for Uganda.

In conclusion, this Chapter begins with an overview discussion of the findings from the feasibility assessments and sustainability assessment of the sanitation system alternatives proposed for **UCU**, which indicated that integrated sanitation system alternatives are both feasible and sustainable. Thereafter, a planning framework for the integrated sanitation system approach was proposed. Information obtained from the various phases of the research, which included the initiation, feasibility assessment and sustainability assessment in addition to a review of existing environmental sanitation planning frameworks enabled the development of the planning framework. Thus, Chapter 13 of this dissertation finally discusses the conclusions and recommendations of this research.

13 Conclusions and Recommendations

Chapter 13 *reflects on the integrated sanitation system approach suggested in this research as a possible solution to organic waste management challenges experienced in urban and peri-urban settings within Uganda. The Chapter summarises the results of the research and gives recommendations for further research.*

13.1 Summary of Research.

Environmental sanitation which basically includes a range of interventions designed to improve management of excreta, sullage, drainage and solid waste is an urgent requirement in urban areas. Globally, the population size is expected to reach 10·1 billion at the end of 21st century (Ezeh et al. 2012). With such population increments, the number of people living in urban areas is expected to increase to atleast 60% of the global population in 2050 (UN 2014b). In Africa alone, an urban population of about 1.23 billion people representing at least 60% of the overall population is projected by 2050 (Maseland and Kayani 2010). The urbanisation trend in Uganda is no different from that of Africa as a region with a recorded urbanisation rate of 17% in 2016, which is projected to increase to 33% in 2050 (Haub and Gribble 2011). Such rapid urbanisation can have adverse implications due the pressure exerted on public services and infrastructure which may not be developed at a similar rate as population increase. Current trends already show that low-income countries, especially in Sub-Saharan Africa have limited public services in key areas of health care, education, sanitation, housing among others. A rapid increase in population requiring the limited services in addition to the often insufficiently trained labor force would quickly aggravate the situation (Ezeh et al. 2012). This implies that planned action for provision of environmental sanitation services among other services should be considered if the projected increase in urbanisation in Uganda is to yield economic development.

Particularly with reference to solid waste management in urban areas in Uganda, research shows that most of the waste collected consists of at least 70% organic material and is mostly transported and dumped in landfills (Okot-Okumu 2012). While separate management of wastewater is accomplished using various systems. Taking into consideration the existing potential of resource recovery from organic waste and the need for environmental sanitation services in urban areas of Uganda, this research set out to explore the feasibility of integrated sanitation systems for the management of organic waste streams. The integrated sanitation system approach, which is based on the environmental sanitation concept, adopts a combined organic waste management rather than the separated waste management approach commonly practiced in urban areas of Uganda. The combined management of human and animal excreta (sewage and faecal sludge, cow dung), organic solid waste and reuse of wastewater effluent using a combination of technologies/processes is considered. Anaerobic digestion (**AD**) in combination with other processes/technologies such as composting, incineration and solar drying among others are considered for in the integrated sanitation systems approach.

The integrated sanitation systems are considered a possible solution for management of organic waste streams in urban and peri-urban with a particular focus for community and town or city domains. This implies that the integrated sanitation system approach could be applicable in schools and institutions of learning, hospitals, housing estates, towns and cities among other areas within Uganda.

Given that the integrated sanitation system approach was based on the environmental sanitation concept, a review of existing environmental sanitation approaches applied in urban areas was carried out. The review highlighted certain gaps within the sanitation approaches and these included; the absence of a systematic way to accomplish the evaluation of sanitation system options. Furthermore, there is no reference to the meaning of a sustainable technology option with regards to a particular context. Moreover, a procedure for the inclusive assessment of sustainability of different sanitation technology alternatives is absent in the approaches, yet most of these environmental sanitation approaches were based on the *Bellagio principles* of sustainable sanitation. Having identified these gaps in the existing environmental sanitation approaches applied for urban sanitation, this research set out to ***explore the feasibility of integrated sanitation systems for urban areas in Uganda***. To inform the research, a case study methodology was adopted, using Uganda Christian University (**UCU**) as the case study area. This research was carried out by answering three research questions also described in Chapter 1 as:

1. Are integrated sanitation systems feasible for urban areas in Uganda?

This research question was answered in two phases which included the initiation and feasibility assessment phases. The initiation phase was informed by demand creation and interest for sanitation service improvement. Moreover, stakeholder input regarding the sanitation problems and other issues pertinent to organic waste management was also informed this phase. Thereafter, detailed assessments of the local context taking into consideration the existing physical and socio-economic environment of the designated area was carried out to obtain a good understanding of the designated. The outcome from the initiation phase enabled the design and suggestion of integrated sanitation system alternatives, which were proposed for **UCU**. Six sanitation system alternatives were designed and these included:

The **Status Quo** alternative**,** which consists of the current sanitation management measures at **UCU**.

The **COMPAD** alternative**;** composting of sewage sludge and organic waste at **UCU +** AD.

The **COMPAD LF** alternative; composting of sewage sludge and organic waste at Mukono Municipal landfill plant+ AD.

The **INCAD** alternative**;** co-incineration of sewage sludge and medical waste **+** AD.

The **INTEG 1** alternative**;** AD**+** solar drying of digestate.

The **INTEG 2** alternative**;** AD **+**solar drying **+**briquetting of dried digestate.

Where AD=Anaerobic digestion

A holistic feasibility assessment approach was then adopted to assess the sanitation alternatives proposed for **UCU**. The feasibility assessment considered four aspects which included; technical, economic, environmental and socio-cultural assessments further discussed within the respective aspect headings.

a) ***Technical feasibility assessment;*** of the sanitation systems focused on the assessment of the functionality of the systems with reference to three criteria, which included robustness, flexibility and system complexity. Technical feasibility assessment was based on expert input, which was elicited using questionnaires. The experts consulted included engineers and professionals in the Water, Sanitation and Renewable Energy sectors from **UCU** and Uganda. The assessment showed that in addition to the **Status Quo** alternative, the **COMPAD LF**, **COMPAD** and **INCAD** alternatives were considered quite feasible with reference to the criteria considered. Moreover, a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis strongly emphasised the attractiveness of all the integrated sanitation system alternatives, which was associated with resource recovery potential of system alternatives.

The technical feasibility assessment highlighted the need for clear definition of system objectives prior to carrying out assessments since this would enable a broader visualisation the sanitation systems irrespective of the tools used for assessment. Premature elimination of sanitation system alternatives based on assessment of a single aspect could also be avoided once definition of sanitation system objectives was carried out. With regards to the integrated sanitation systems, the main objectives of the systems are management of organic waste streams and recovery of resources from management of waste streams. Once the objectives of the sanitation system are clearly defined, supporting tools such as **SWOT** analysis may be useful to further inform technical assessments. Incorporation of **SWOT** analyses may become much more crucial in cases where sanitation system upgrades are envisioned since integrated sanitation systems may seem technically more demanding than the conventional sanitation system, creating a bias towards conventional systems.

a) ***Environmental feasibility assessment;*** considered the evaluation of resource utilisation by the system, impact on the environment and resource recovery from the sanitation systems. Using life cycle assessment methodology, the environmental feasibility assessment was represented by the overall impacts to the environment from the each of the sanitation system alternatives. The results for the assessment indicated that a positive correlation exits between resource recovery and environmental performance of sanitation system alternatives. Thus, the more resources were recovered, the lower the environmental impact a sanitation system alternative had. All integrated sanitation system alternatives registered much lower environmental impact than the **Status Quo** alternative. Potential resource recovery from the integrated sanitation system alternatives was in the form of biogas, compost and digestate as organic fertilizer as well as briquettes made from digestate.

With reference to the integrated sanitation system alternatives, the **INTEG 2** alternative, which additionally considered recovery of briquettes from digestate registered the least environmental impact. Moreover, the results also revealed that minimising biogas leakages (fugitive emissions) from the anaerobic digestion process to at most 3% of the biogas produced would further result in much lower environmental burden for the integrated sanitation system alternatives.

Particularly, global warming potential and photochemical ozone creation potential impacts would be reduced in case biogas leakages from anaerobic digestion unit were reduced. Therefore, in case integrated sanitation systems are considered for any other entity i.e hospitals, institutions, housing estates cities etc., the sanitation systems would have reduced environmental impact, especially since biogas would be utilised for other purposes. Moreover, ensuring minimal biogas emissions from the anaerobic units would further boost the overall environmental performance of the integrated sanitation systems.

The findings from the **LCA** for **UCU** also illuminated certain key aspects that can be considered in case of environmental assessment of integrated sanitation systems. Firstly, a clear break down or definition of the integrated sanitation system goal would be necessary to further inform the assessment. For instance, prior understanding the mode of resource utilisation would be crucial. Thus some important questions to ask would be *if the biogas produced would be used for cogeneration or other purposes or whether the digestate produced would undergo post treatment*. Prior appreciation of such information in addition to clear definition of other processes considered within the sanitation systems would be crucial since such information influences the overall performance of specific sanitation systems once modeled in **LCA** supporting tools or software.

Furthermore, assumptions considered during the assessments of the sanitation systems for specific entities should also be clearly documented. This is because incorporation of the various assumptions during assessments using **LCA** software could also influence the overall results. Besides, the absence of representative datasets can be a main limitation to the **LCAs** and this has to be taken into consideration. For instance, most **LCA** soft wares do not have Africa regional data as such, during modeling, data sets for specific processes used may originate from developed countries or other data sets considered relatively close to the regional (Africa) conditions. This limitation can inherently influence the results of an **LCA** since in most cases data sets from developed countries incorporate the most recent /modern technologies, which additionally include emission mitigation measures. Once such data sets are used for modeling sanitation systems used in Uganda, actual reflection of the situation may not be fully achieved, influencing the overall **LCA** result. Thus, in case region specific data is obtained in future assessments, then variation in **LCA** results for integrated sanitation system can be expected.

b) ***Economic feasibility assessment;*** linked the impacts of poor sanitation to economic losses while at the same time arguing a business case for a sanitation system out based on the economic returns. The economic returns were associated with reducing the burden of health, environmental issues as well as citizens' lost time and productivity due to poor health caused by poor sanitation. The economic feasibility of the sanitation system alternatives was investigated based on a cost benefit approach.

Furthermore, investigation of parameters such as Net Present value (**NPV**), Internal Rate of Return (**IRR**) and Payback Period (**PBP**) was carried out to inform the feasibility assessment. The results revealed that the economic feasibility of the sanitation systems proposed for **UCU** was also influenced by a combination of resource recovery and avoided installation costs. As such, sanitation system alternatives which considered resource recovery and additionally had lower overall costs due to avoided installation costs performed well. The results showed that the **COMPAD LF** alternative was the most economically feasible option. This alternative additionally considered utilisation of the composting plant unit at Mukono Municipal landfill instead of installing an own composting plant at **UCU**. Besides, resources in the form of biogas, compost and digestate were also recovered from this alternative.

Moreover, reduction of fugitive emissions from the anaerobic digestion unit to at most 3% biogas produced resulted in much better performance of integrated sanitation system alternatives. Reduced biogas emissions implied that additional biogas would be available for untilisation or cogeneration as such, more revenue would be accrued, improving the overall system performance. Besides, the assessment also showed using an interest rate of at most 10% and an equity capital of at least 30% positively influenced the feasibility of the integrated sanitation system alternatives. Absence of equity capital reduced the number of feasible integrated sanitation alternatives to only **COMPAD LF** and **INTEG 2** due to slightly lower overall costs and increased resource recovery respectively.

With reference to integrated sanitation systems for other entities, the results from the economic assessment for **UCU** highlighted key aspects for consideration. Firstly, since the economic feasibility of integrated sanitation systems is dependent on increased annual revenues from the system, then additional resource recovery from the management of the organic waste should be promoted. Furthermore, where possible, already existing system components should be used. For instance, instead of installing a new incineration unit or composting plant, using existing units would result in avoided installation costs. Such scenarios can be considered for hospitals, cities and towns, which may already have well-built incinerators. While collaboration with city and town authorities to use existing composting plants located in certain landfills within Uganda could positively influence the economic feasibility of integrated sanitation systems installed by say housing estates, institutions or other private entities within urban areas. Undoubtedly, such collaborations should be clearly governed by supporting documents such as memoranda of understanding and contracts or agreements, which would clearly define roles and expectations of involved parties.

Besides, with reference to resource recovery in the form of biogas, further reduction in biogas leakage to at most 3% would imply more biogas is available for direct utilisation or cogeneration and this would contribute to increased annual revenue. The avoided environmental impact associated with utilisation of biogas generated from management of organic waste streams can be translated into returns from reduction in greenhouse gas (**GHG**) emissions. Thus, registering the integrated sanitation systems as **Clean Development Mechanism** (CDM) projects would imply that income from carbon offsets would be obtained, increasing the overall revenues accrued by the sanitation system. Meanwhile, with reference to digestate utilisation, an understanding of the priorities of the responsible entity would in turn influence resource recovery and revenues accrued. For instance, in case housing estates or institutions are interested in utilisation of briquettes instead of charcoal, then resource recovery from digestate can be focused towards briquette making rather than use as organic fertilizer. On the other hand if the sanitation system is located in a peri-urban areas where there is available land for agriculture or if there is a high demand for soil conditioner/organic fertilizer from landscape business owners in the cities and towns, then the utilisation of digestate as organic fertilizer may be preferred.

Moreover, the findings from the economic feasibility for **UCU** also highlighted that investment of equity capital of at least 30% would generally imply that more integrated sanitation system alternatives can be considered economically feasible. While the absence of equity capital for investment could limit the number of integrated sanitation system options to select from. Moreover, considering an interest rate of up to 10% could also imply that a broader list of integrated sanitation system options can be considered for comparison. This would in turn allow for flexibility in decision making regarding the sanitation system alternatives. Nevertheless, variation in discount rates to incorporate the local conditions within a particular setting should be considered since the overall economic feasibility represented by the **NPV, IRR** and **PBP** would reflect any identified changes.

Furthermore, the overall economic feasibility of integrated sanitation system alternatives will surely be influenced by the variable installation costs of components within sanitation systems. Often the case, variable considerations for components within the system may exist, especially for components such as the anaerobic digestion unit where pre-treatment and post treatment units may vary in component composition. As such, the overall component costs may vary and this can further be influenced by supplier quotations, which also vary. Noteworthy is that variable design considerations for the different components within the sanitation system may be considered and this would also influence the overall economic feasibility of the sanitation system.

The ***Socio-cultural assessment****;* took into consideration the acceptance of sanitation systems and the institutional/regulatory requirement. A combination of stakeholder analysis and surveys were used to enable the assessment.

The stakeholder analysis enabled identification of stakeholders, the definition of their roles, interests and influence with reference to the proposed sanitation system value chains. The stakeholder analysis highlighted the importance of regulatory bodies such as National Environment Management Authority (**NEMA**) and National Water & Sewerage Corporation (**NWSC**). These bodies would be responsible for availing the necessary approval and compliance checks for the sanitation system with reference to standards and policies. Moreover, opportunities to obtain advice/experience from other Non-governmental organisations (NGO`s) such as **GIZ** and Water for the People exist. This are some of the NGOs involved in implementation and research in areas related to those suggested for the integrated sanitation system approach. The prominent role played by **UCU** was also highlighted in the stakeholder analysis. As such, a stakeholder survey for **UCU** was carried out to examine the acceptability of sanitation system alternatives. The acceptability of sanitation systems was defined by *user perception* and the *level of convenience* attached to the systems.

The results from the survey with reference to the integrated sanitation system alternatives indicated that the respondents registered reservation in utilisation of biogas and organic fertilizer, which would be generated from faecal matter. Negative connotations associated with potential contamination of food by biogas generated from sewage/faecal matter and reservations in using organic fertilizer from similar sources were cited. Moreover, concerns related to potential odour and noise nuisance from the system alternatives also contributed to the low level of *convenience* attached. This eventually significantly influenced overall sanitation system acceptability. Thus, with reference to the integrated sanitation system alternatives suggested for **UCU**, the **INCAD**, **COMPAD LF** and **COMPAD** alternatives registered much better acceptability than the **INTEG 1** and **INTEG 2** alternatives. These results exposed the requirement for sensitisation and raising awareness regarding utilisation byproducts from integrated sanitation systems. This is because the acceptability of the system alternatives was strongly influenced by the respondents cultural beliefs related to use of byproducts from the systems.

A review of the regulatory requirements indicated that there are existing regulations, policies, standards and ordinances that can be referred to with regards to the scope of integrated sanitation system approach suggested in this research. However, there is need for more specific regulations, especially with reference to bio-solids (from faecal matter) application on land and other possible uses of biosolids in aquaculture. Moreover, air quality regulations specific for incinerators would also be necessary in case co-incineration of sewage sludge with other waste streams is considered.

Overall, the findings from the socio-cultural assessment for **UCU** emphasised the importance of stakeholder analyses as a key component for socio-cultural assessment of integrated sanitation systems. Although there are bound to be variable stakeholder groups depending on the entities involved or implementing the integrated sanitation system approach, certain stakeholder groups may be common to most domains considered.

Stakeholder groups such as local authorities, regulatory bodies, NGO`s, funding organisations and contractors among others may be common to all domains considered. Moreover, the level of power or control these stakeholder groups could have may vary with the different urban domains considered. Besides, the level of skill required within a particular integrated sanitation system and the available human resource may also influence the control or power wielded by specific stakeholder groups.

Furthermore, appreciation of the sanitation system`s main goals, especially in relation with system by-product utilisation could also influence the control or power wielded by benefactors for instance. Given that the stakeholder analysis process is also an iterative process applicable at various stages of planning and possibly implementation of the integrated sanitation systems, the process is bound to evolve. As such, new stakeholders may be included at latter stages and relevant changes reflecting the interests, roles and influence of new stakeholders should be incorporated. Moreover, since clear description of stakeholders is achieved from the analysis, the process plays an anticipatory role for integrated sanitation system implementation.

In carrying out the socio-cultural assessment of integrated sanitation systems for different entities, the acceptability of the systems may be influenced by a range of aspects from public health and environmental impacts concerns to expectations from by-product utilisation. Moreover, since the integrated sanitation system approach considers management of faecal matter, organic waste and wastewater effluent, concerns related to public health risks are bound to increase. Therefore, perception, attitude and behaviour will inherently be influenced by culture. As such, sensitisation and raising awareness about the sanitation systems as well as about utilisation of by-products would be crucial to boosting acceptability of integrated sanitation systems amongst potential users.

Furthermore, reference to regional, national and local regulatory framework is crucial for system acceptability since failure to comply with existing regulations could lead to rejection of the systems. In cases where there is absence of necessary national or local regulations, for instance with regards to biosolid application on land, then reference to regional regulations such as those stipulated by the European Union among others can be considered. Moreover, collaboration with other actors already involved in production of soil conditioner or fertilizer from similar waste streams such as **NWSC** can be considered. Collaboration with such entities could also contribute to the development of national or local guidelines for checking quality of such biosolids within the country. Also, by developing an institutional framework, additional collaboration opportunities could exist amongst various actors and NGO`s or research institutions.

Taking into consideration the results from the feasibility assessment of all four aspects, the **COMPAD LF** alternative stood out as the most feasible sanitation system alternative. Given that this research adopted a case study approach, which basically investigates a contemporary phenomenon within its real life context, the performance of the **COMPAD LF** with reference to all aspects suggested that integrated sanitation systems are feasible.

Without a doubt, the local context of various entities for which integrated sanitation systems are considered is a crucial component during the assessment. Moreover, from the holistic feasibility assessments carried out, interlinkages between the four aspects considered were identified. Public health concerns associated with management of the organic waste streams and utilisation of system by-products influenced sanitation system acceptability. The reduction of environmental impacts from the management of organic waste streams represented as carbon offsets also influenced the economic feasibility as well as acceptability of the sanitation systems. Furthermore, technical aspects of the sanitation systems defined by system complexity or skill requirement could in turn influence system acceptability, especially in cases where the responsible entities would be expected to operate and manage the systems. Therefore, to further appreciate the interdependency between the aspects, the sustainability assessment of sanitation systems proposed for **UCU** was carried out.

2. Are integrated sanitation systems sustainable?

The sustainability assessment of sanitation system alternatives proposed for **UCU** was carried out using multi criteria decision analysis. A participatory approach was incorporated in the sustainability assessment of the sanitation system alternatives. Thus, a combination of findings from the feasibility assessments, input from stakeholders and reference to the Helmholtz integrative concept of sustainability informed the sustainability assessments.

The results from the sustainability assessment revealed that even though the **Status Quo** alternative registered the highest overall sustainable value, the **COMPAD LF** alternative was the most selected alternative in case various trade-offs between the four aspects were considered. This implied that irrespective of the trade-off between aspects considered, the **COMPAD LF** alternative was the most reliable one. Moreover, other integrated sanitation system alternatives were also optimal when variable trade-offs between aspects were considered. As such, the results indicated that integrated sanitation systems were sustainable, answering the 2nd research question.

In general, the sustainability assessment for sanitation system alternatives proposed for **UCU** exposed key aspects to consider when carrying out similar assessments. Prior to carrying out the assessment, a clear definition of the sanitation system purpose or objectives is necessary since this could influence the aspects, criteria and even indicators considered during the assessment. Given that a participatory approach may be adopted in carrying out the sustainability assessment using multi-criteria decision analysis, selection of participants and continually communicating relevant information to them becomes a crucial factor, which eventually promotes transparency in the decision making process.

Moreover, in addition to carrying out sensitivity analyses, having an overview of expectations from the assessment may offer the necessary guidance to the whole process. As such, irrespective of the domains for which the integrated sanitation system approach is considered i.e. communities, cities or towns, a person(s) with experience on how to carry out the sustainability assessment is crucial for the team involved in the entire planning and implementation process. Given that sustainability assessment of integrated sanitation system alternatives can also enable ranking of alternatives, the rigorous process can be slightly modified to incorporate minor changes, especially in cases where similar case study areas are considered. This would reduce the time required to carry out assessments.

Having identified the potential of application of the integrated sanitation system approach in peri-urban and urban areas in Uganda, a planning framework for the approach was proposed, answering research question 3.

3. **What are the main steps required in the planning of integrated sanitation systems?**

The input from all phases of the research i.e. the initiation phase, feasibility and sustainability assessment phases informed the development of a procedure to enable planning of the integrated sanitation systems. Moreover, reference to already existing environmental sanitation planning tools also informed the development of the planning framework for the integrated sanitation system approach. The planning framework proposed consists of 8 steps, which broadly emphasise a participatory approach, feasibility and sustainable assessment of alternatives as well as capacity building aspects. The overall goal of the integrated sanitation system approach planning framework is to give necessary guidance. Thus, it is expected that the planning framework will simplify the planning process and enable wide spread future implementation of the integrated sanitation system approach in Uganda. Table 13-1 gives a summary of the steps suggested for the planning framework.

Table 13-1: Suggested Steps for the Integrated Sanitation System Planning Framework

Context assessment	Process initiation and demand creation
	Launch of planning process
	Assessment of current situation and prioritisation of problems
System alternatives and assessments	Identification of system alternatives and feasibility assessment
	Sustainability assessment of alternatives
	Application of demonstration units
Implementation	Implementation
	Monitoring and evaluation

Source: Author

Therefore, it can be concluded that in case an integrated sanitation system is considered for any of the entities within peri-urban and urban areas in Uganda, then the procedure shown in Figure 13-1 can generally be considered. Specifically, for effective planning and implementation of integrated sanitation systems, four key elements are crucial and these include: context assessment, feasibility assessment of sanitation system alternatives, sustainability assessment of sanitation system alternatives and inclusion of a participatory approach.

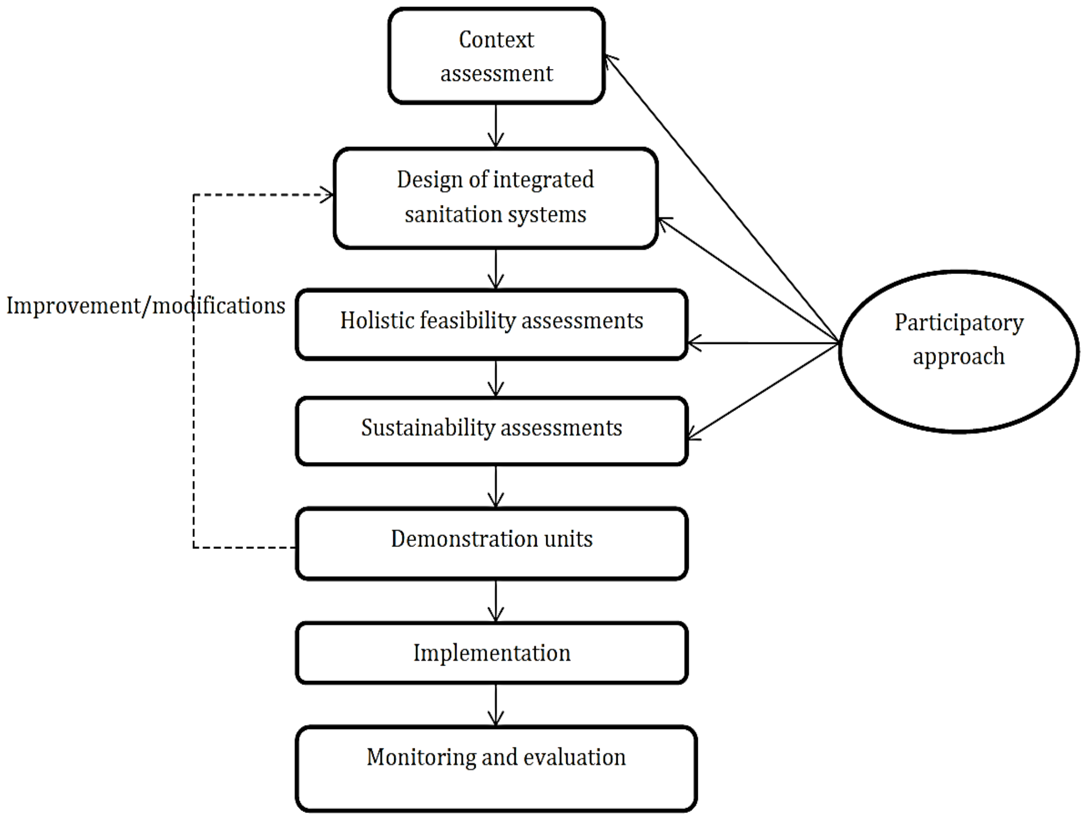

Figure 13-1; Procedure for planning and implementation of Integrated Sanitation Systems
Source: Author

In addition to incorporating key aspects of sanitation such as technology, environment, financing, socio-cultural, the integrated sanitation systems also specifically focus on organic waste management, with the additional objective of resource recovery. In so doing, the sanitation systems could be a solution to organic waste management challenges that are faced in urban/peri-urban settings in Uganda, with the possibility of application in areas having similar settings within Sub-Saharan Africa.

Moreover, by incorporating holistic feasibility and sustainability assessments within the planning of integrated sanitation systems, the research fills the gaps initially identified in existing environmental sanitation planning tools. By inclusion of demonstration units within the planning procedure, the possibility to make informed improvements or modifications to the sanitation system designs prior to final implementation and scaling up exists. This not only enhances capacity building but will also raise awareness regarding the integrated sanitation system approach, which highlights a sanitation-energy-agriculture nexus. Such a nexus would make sanitation management more attractive in urban areas of Uganda. Moreover, on a larger scale the research findings can contribute to the development of specific policies to enable the implementation of sustainability development goals for sanitation in Uganda and other nations which may have similar urban settings. Hence, it would be prudent to say this research contributes to the body of knowledge.

1.1 Future Research Perspectives

Despite suggesting an approach for organic waste management mostly in urban and peri-urban settings in Uganda, further research can be carried out for the improvement of the proposed integrated sanitation system approach in some of the areas cited:

a) Stakeholder involvement in the entire planning process.

Taking into consideration that the integrated sanitation system approach is suggested for community and town or city domains within urban environments, a clear understanding of the level of stakeholders' participation is crucial. Stakeholder participation should incorporate variability that could occur based on region, cultural setting and political systems in a specific context. For instance, the institutional settings may vary widely from considerations for city integrated sanitation systems as such, understanding the approaches followed i.e. whether a top-down approach or bottom-up approach is the common practice becomes extremely relevant. This would also be extremely relevant in case the integrated sanitation system approach is considered in other areas within Sub-Saharan Africa. Incorporation of these aspects is crucial because the participation of beneficiaries' or system users could be limited or influenced by the authority placed in a higher echelon. While reflection of cultural aspects revealed through religious views, behaviour, habits could significantly influence stakeholder participation. Therefore, to avoid conflict, biased response, passive involvement or delayed response through the planning process, prior understanding of environment and its characteristics would inform stakeholder participation. Such in-depth understanding of stakeholder participation calls for further research taking into account the local context.

b) Project champions

The integrated sanitation system approach considers combined management of organic waste streams and resource recovery as such, a complex or much broader system value chain can be expected. Involvement of various stakeholder groups based on the scope of system chain is inevitable and thus, identification of a project champion is crucial.

The project champion(s) who could be an individual, authority or organisation would have to be well informed of the approach and additionally be able to coordinate, manage and in other cases steer the project. Again, reflecting on the various domains for which the integrated sanitation system approach is considered applicable, prior identification and possibly continuous training of project champions would be necessary as the project develops. Further research in this area would avail necessary information on the possible challenges expected or anticipated as the integrated sanitation system project evolves. Moreover, the team involved in planning and implementation of the project should include a person(s) with knowhow in carrying out sustainability assessments since this is a key component of the whole process.

c) Methodology or tools used for assessment of sanitation alternatives

A holistic feasibility assessment approach and sustainability assessments are considered for integrated sanitation system alternatives thus, various methods or tools are used for the assessments. With reference to the feasibility assessments, the methods used are dependent on the aspects considered moreover, various methods may be applicable for assessment of a single aspect. For instance, assessment of environmental aspects could be also achieved by environment impact assessment methods rather than life cycle assessment. While in case other aspects like health are also considered, then risk assessment methods may be used. Besides, other methods apart from multi criteria decision analysis could also be considered for sustainability assessment. Therefore, it is recommended that the teams involved in planning for an integrated sanitation system approach should carry out own preliminary investigations to identify which methods can be applied during the holistic feasibility assessments and sustainability assessments.

d) Sensitisation and raising awareness

During the assessment of the integrated sanitation systems, a holistic approach is adopted which includes assessment of technical, environmental, economic and socio-cultural aspects among others. In carrying out the respective assessments, sensitisation and awareness raising may be required depending on the stakeholders involved. Although it is easily considered at the initial stages of the project, sensitisation and raising awareness may also be required during the feasibility/sustainability assessment as well as application of demonstration units' stages since stakeholder involvement is equally crucial at these stages. An example could be in cases where feedback from demonstration units has to be clearly explained prior to final implementation. In such cases, sensitisation or raising awareness of different stakeholder groups would be necessary. Therefore, further research to inform on requirements and extent of sensitisation and raising awareness is necessary.

e) Differing perspectives of stakeholder groups

This may be specifically visible during feasibility and sustainability assessment of sanitation system alternatives. With regards to feasibility assessments, additional supporting tools such as strength, weakness, opportunities, threats (SWOT) analysis can be additionally considered to further inform assessments. With reference to sustainability assessments, once a set of criteria and indicators have been identified, assigning of scores and weights will most often reflect the different sustainability perspectives from the stakeholder groups.

Although sensitivity analyses can be used to reflect the different stakeholder perspectives, a better method of dealing with these differing perspectives could be further developed. This would be especially relevant in the event that a large number of stakeholder groups are involved at the **MCDA** stage and variable perspectives are obtained. Representing the variable perspectives using simple sensitivity analyses may become burdensome. As such, a mathematical procedure could be considered to formulate algorithms to compute the sensitivity analyses which could incorporate aspects such as;

- The effect of variation of weights assigned to criteria and indicators by the stakeholders on the results of trade-offs considered in comparing sanitation system alternatives.
- The influence of the ranking of criteria and indicators by stakeholders on the final selection of sanitation system alternatives.

f) Integrated Sanitation System planning and implementation framework steps

The planning framework for integrated sanitation systems consists of 8 steps and begins with process initiation and demand creation. Depending on the domain for application of sanitation approach, starting the planning process with the initiation step may not always be the norm. For instance, inner city areas may not require process initiation since projects may be started by government authorities and potential users could be informed or are directly involved in various activities related to the integrated sanitation systems. Similarly, the Launch of planning process could also be skipped since in certain cases it could be incorporated within the Initiation step. Moreover, in certain cases where upgrading of a sanitation system may be required, construction of demonstration units may not be necessary thus the step can be skipped. Therefore, further research maybe necessary to guide, modify or improve the planning and implementation framework taking into consideration the local context considered.

g) Documentation of experiences or research

Finally, it is also recommended that documentation and dissemination of knowledge obtained from various related research and experiences be considered since this could contribute to informing the development of the much needed regulatory framework to support the integrated sanitation approach in Uganda. Involvement of government ministries in supporting related research and documentation could be one of the avenues through which documentation of experiences from related research and dissemination of knowledge can be attained. For instance, documentation of and dissemination of information from management of faecal sludge at existing treatment plants within the country, specifying the quality of soil conditioner obtained and sold could contribute to the development of national standards or regulations for biosolid quality. Moreover, collaboration with other NGO`s and institutions involved or interested in relevant research areas could further contribute to the development of much needed regulations.

Also, through dissemination of information from related research, guidance on necessary institutional framework relevant for an integrated sanitation system approach could be obtained and this would enable better planning and implementation of the proposed approach.

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Appendices

Appendix 1: Conventional Wastewater treatment

Wastewater treatment systems are a result of integration of operations and processes in use. Interchangeable use of unit processes and operations is common although, (Metcalf and Eddy 2004) clearly define three main groups commonly considered during wastewater treatment in wastewater treatment plants and these include;

Physical unit operations; here treatment of wastewater occurs due to, or through application of physical forces such as screening, mixing, flocculation, sedimentation, floatation and filtration.

Biological unit operations; these treatment methods mainly remove contaminants using biological activity. Examples of biological activity treatment include carbonaceous organic removal, nitrification and denitrification among others.

Chemical unit operations; here treatment methods involving removal or conversion of contaminants are carried out by addition of chemical products or due to chemical reactions such as precipitation, disinfection and absorption (Metcalf and Eddy 2004; Marcos von Sperling 2007). Within the different groups of operations mentioned, variable technologies or mechanisms can be used separately or concurrently to remove pollutants in wastewater. Some of the key mechanisms used for pollutant removal in wastewater treatment are summarised in Table 1.

Table 1: Main mechanisms for removal of pollutants in wastewater treatment

Pollutant group	subdivision	Process	Removal mechanism
Solids	Coarse solids (>~1cm)	Screening	Retention of solids with dimensions greater than the spacing between bars
	Suspended solids(>~1μm)	Sedimentation	Separation of particles with a density greater than sewage
	Dissolved solids(<~1μm)	Adsorption	Retention on the surface of biomass flocs or biofilms
Organic matter	BOD in suspension (particulate BOD)(>~1μm)	Sedimentation Adsorption	Similar to case of solid removal mechanism
		Hydrolysis	Conversion of BOD in suspension to soluble BOD by means of enzymes, allowing stabilization
		Stabilisation	Utilization of biomass with conversion into gases, water and other inert compounds
	Soluble BOD(<~1μm)	Adsorption Stabilisation	Similar to particulate BOD (>~1μm)
Pathogens	Larger dimension with protective layer(protozoans, cysts and helminth eggs)	Sedimentation	Separation of pathogens with larger dimensions and density greater than sewage
		Filtration	Retention of pathogens in filter medium with adequate pore size
	Lower dimensions (bacteria and Viruses)	Adverse environmental conditions	Temperature, pH, lack of food, competition with other species, predation
		Ultraviolet radiation	Either radiation from the sun or artificial source
		Disinfection	Addition of disinfecting agent, such as chlorine
Nitrogen	Organic nitrogen	Ammonification	Conversion of organic nitrogen to ammonia
	Ammonia	Nitrification	Conversion of ammonia to nitrite, thereafter to nitrate using nitrifying bacteria
		Bacterial assimilation	Incorporation of ammonia the composition of the bacterial cell
		Stripping	Release of ammonia in to the atmosphere under high pH conditions

		Breakpoint chlorination	Conversion of ammonia to chloramines through addition of chlorine
	Nitrate	Denitrification	Conversion of nitrate into molecular nitrogen, which then escapes to the atmosphere, under anoxic conditions
Phosphorus	Phosphate	Bacterial assimilation	Assimilation in excess of the phosphate from the liquid by phosphate accumulating organisms, which takes place when aerobic and anaerobic conditions are alternated
		Precipitation	Phosphorus precipitation under conditions of high pH, or through the addition of metallic salts
		Filtration	Retention of phosphorus-rich biomass, after stage of biological excessive P assimilation

Source: (Marcos von Sperling 2007)

Appendix 2: Questionnaires and Checklists used for Collection of Baseline Information.

Various Key informants were consulted to obtain relevant baseline information. Table 2 gives an overview of the stakeholders consulted.

Table 2: Summary of Key Informants Consulted to Obtain Baseline Information

No.	Key Informant/source	Entity/Institution
1	Engineer WWTP at UCU	UCU
2	Director Facilities & Capital Projects at UCU	UCU
3	Head Catering/Kitchen section at UCU	UCU
4	Students and Hall of Residence Wardens	UCU
5	Teaching and Non-Teaching Staff	UCU
6	Mukono Municipality Environment officer	Mukono Municipality
7	In charge Biogas Section	GIZ
8	Projects Officer/Engineer	Water for the People
9	Environment and Energy Engineer	National Environment management Authority(NEMA)
10	Biomass Energy Officer	Ministry of Energy & Mineral Development(MEMD)
11	Plant Engineer	NWSC Faecal Sludge Plant, Lubigi
12	Quality Assurance Manager	NWSC Faecal Sludge Plant, Lubigi
13	Engineers, Consultants	Uganda National Biogas Association
14	Coordinator	Appropriate Technology Centre for Sanitation & Water
15	Consultant	EAWAG
	Consultants in Sanitation, water, biogas energy recovery(briquetting)	SNV, Briketi, SSWARS

Source: Author

Sample of the checklist and questionnaires used to elicit baseline information is included.

Check list for data collection at Uganda Christian University.

This check list will guide in data collection at the University giving a clear understanding of existing systems. The University wastewater treatment plant and organic waste sources are of key interest. Direct observation, carrying out of informal interviews and measurements particularly of waste are some of the tools which applied at this stage. This information will inform latter phases of the research

WWTP

1. When was the Wastewater treatment plant (WWTP at the University installed?
2. What is the expected life time of the WWTP?
3. How far from the University main infrastructure is WWTP located?
4. How much space does the plant cover?
5. Is there land available for possible expansion?
6. What are the main treatment components of the WWTP?
7. What is the treatment capacity of the WWTP at UCU on a daily basis?
8. What is the composition of wastewater at the entry to the plant?
9. How is the effluent at the plant finally disposed?
10. How is the sludge generated from the plant finally disposed of?

Solid waste management

11. What is the estimated amount of solid waste generated at the University daily?
12. What solid waste management measures are in place at University?
13. What is the composition of organic waste in the overall solid waste?
14. Which are the main sources of organic waste at University?
15. How much organic waste is generated from each of these sources on a weekly basis?
16. What is the main composition of the organic waste generated daily?
17. How much of the organic waste passes through unofficial channels?

UCU Directorate of Facilities & Capital Projects

This questionnaire is designed to obtain information for a PhD research on the ***feasibility of an integrated sanitation system for Uganda Christian University- Mukono***. In this research, the integrated sanitation system considers combined management of wastewater treatment by-products and organic solid waste. Wastewater at the University is treated in an activated treatment plant while organic waste is separately managed .This research attempts to check the feasibility of combined management of sludge from the treatment plant and organic waste for resource recovery. In this study, sustainability assessment of the integrated sanitation system is proposed hence environmental, social, economic, technical, intuitional/regulatory aspects will be assessed. The proposed integrated sanitation system considers co-digestion of sludge and organic waste in an anaerobic digester and possible reuse of effluent from the wastewater treatment plant for non-portable purposes. Biogas and digestate which could be used as fertilizer are the main by-products of such a system. Based on this background, the following questions attempt to obtain information on the University demographics, relevant infrastructural development, related installation cost, energy demand and future project development. All information obtained will be treated with confidentiality and the questionnaire destroyed after use. Your contribution to this research is highly appreciated.

Demographics

1. What is the current population at Uganda Christian University (UCU)?

2. What is the projected annual increase or decrease in population?

Wastewater treatment plant (WWTP)

3. What is the expected life time of the WWTP?
4. What is the spatial coverage of the WWTP (plan)?
5. Are there any future plans for expansion, if yes please state them?
6. In case of future expansion, how much space is available within the WWTP location?

Solid waste management

7. How much waste is generated from the University daily?
8. Which entities contribute the largest amount of waste generated from the University?

9. What is the percentage contribution of organic waste from the overall waste generated daily?

10. What infrastructure is in place for solid waste management at the University?

11. Which specific measures/infrastructure are in place for management of organic waste, at the University?

12. Are there future plans to improve/modify measures in place for waste management?

13. How is final disposal of waste achieved i.e?
    - Organic waste from Kitchen
    - Waste from halls of residence
    - Waste from classroom & office cleaning
    - Compound maintenance
    - Other sources
14. What were the installation cost ranges for ;
    - WWTP
    - Waste management infrastructure in place?

15. What was the main source of funding for installation of these infrastructures?

16. How much fuel is used daily for?
    - Running waste management equipment
    - Transportation of waste for disposal

17. What is the daily expenditure incurred during?
    - Operation of waste management equipment
    - Transportation of waste for disposal

Energy demand

18. What is the daily energy demand in terms of electricity for the;
    - Entire University
    - WWTP
    - Kitchen/dinning
    - Halls of residence
    - Classrooms and offices
19. Which power backup measures are in place within the University?
    - Halls of residence
    - Classrooms & Offices
    - Others

20. What is the monthly energy/ fuel requirement for the power backup infrastructure in place?

21. Are there any plans to install substitute power/energy supply units at the University, if yes please mention them?

Project development

22. Have there been plans to establish any biogas related projects, if yes, what is the current status?

23. What challenges/delays have been met in relation to biogas project development?

24. Are there any other plans to implement wastewater & solid waste management projects within the University, if so please describe them?

25. What are the general procedures/requirements for project development within the University?
26. What other challenges have limited similar project development within the University?

27. What has been the University`s relationship with local authorities like Municipality in relation to various project development?

Other Questionnaires samples

Ministry of Energy- Renewable Energy Division

This questionnaire is administered to obtain information for a PhD research on the ***feasibility of an integrated sanitation system for Uganda Christian University- Mukono***. In this research, the integrated sanitation system considers combined management of wastewater treatment by-products and organic solid waste. Wastewater at the University is treated in an activated treatment plant while organic waste is separately managed .This research attempts to check the feasibility of combined management of sludge from the treatment plant and organic waste for resource recovery. The feasibility study also intends to carry out a sustainability assessment where environmental, social, economic, technical, intuitional/regulatory aspects of the system will be considered. The proposed integrated sanitation system considers codigestion of sludge and organic waste in an anaerobic digester and possible reuse of effluent from the wastewater treatment plant for non-portable purposes. Biogas and digestate which could be used as fertilizer are the main by-products of such a system. Based on this background, the following questions attempt to obtain information on the development of biogas projects, application of codigestion for biogas generation, regulatory requirements for establishment of such a project, possible use and distribution of energy generated from the proposed system. All information obtained will be treated with confidentiality and the questionnaire destroyed after use. Your contribution to this research is highly appreciated.

Biogas contribution

1. What is the current status of renewable energy development/contribution to the national energy demand in Uganda?

2. What are the future projected biogas energy contributions to the energy demand nationally (energy plan);

3. What has been the distribution of the biogas energy projects for;
   - Government led projects

   - Private owned projects

4. How many waste for recovery biogas generation projects have been commissioned by the Ministry over the last 5 years?

Codigestion & Regulatory requirements

5. Has codigestion of substrates for biogas generation been applied in any of the commissioned projects?

6. Which regulations/standards govern establishment of anaerobic codigestion projects in the country?

7. What are the Ministry`s procedures for the establishment of such a project by a private entity like Uganda Christian University (**UCU**)?

8. For a private entity like **UCU**, what would be the regulatory requirements for;
   - Biogas quality generated
   - Own use of energy (heat & electricity) generated from biogas
   - Distribution/sale of generated energy to potential customers

9. Over time, what challenges have been noted to deter the establishment of similar projects for institutions like UCU?

10. What incentives are in place to encourage establishment of similar projects?

11. Which institutional structure is in place to enable dissemination of similar projects within the country?

12. Which factors can be considered for improvement of similar project dissemination?

Mukono Municipality - Environment Office **(Qnr 02; MMEO)**

This questionnaire is designed to obtain information for a PhD research on the ***feasibility of an integrated sanitation system for Uganda Christian University- Mukono***. In this research, the integrated sanitation system considers combined management of wastewater treatment by-products and organic solid waste. Wastewater at the University is treated in an activated treatment plant while organic waste is separately managed .This research attempts to check the feasibility of combined management of sludge from the treatment plant and organic waste for resource recovery. In this study, sustainability assessment of the integrated sanitation system is proposed hence environmental, social, economic, technical, intuitional/regulatory aspects will be assessed. The proposed integrated sanitation system considers codigestion of sludge and organic waste in an anaerobic digester and possible reuse of effluent from the wastewater treatment plant for non-portable purposes. Biogas and digestate which could be used as fertilizer are the main by-products of such a system. Based on this background, the following questions attempt to obtain information on management of waste, operational sanitation systems within the municipality, regulatory framework and expectations of the Municipality for establishment of projects related to resource recovery from waste. All information obtained will be treated with confidentiality and the questionnaire destroyed after use. Your contribution to this research is highly appreciated.

1. What is the population of Mukono Municipality?

2. How is waste managed within the Municipality i.e
    - Solid waste
    - Wastewater

Solid waste

3. What is the percentage composition of organic solid waste from the overall waste collected at the Municipality on a daily basis?

4. What measures are in place for management of organic fraction of the municipal waste (OFMSW)?

5. What are the main challenges experienced in management of organic waste at the municipality?

6. Are there any projects involved in resource recovery from organic waste;
    - Managed by municipality
    - Privately managed
7. What are the main procedures for the establishment of such projects within the municipality?

8. What are the known benefits accrued from these projects?

Sanitation systems

9. Which other sanitation systems are operational within the Municipality?

10. What are the future plans regarding improvement of sanitation systems in the municipality?

11. Are there any integrated sanitation systems operational within the Municipality?
    - Household

    - Institutional

12. What are the main challenges hindering implementation of integrated sanitation systems within the Municipality?

13. What are the Municipality`s requirements for implementation of an integrated sanitation system by an institution like UCU?

14. Which regulations/standards are in place to support implementation of such systems?

15. What institutional framework is in place to support this cause (integrated sanitation systems)?

16. What incentives are in place to support implementation of similar systems within the municipality?

Appendix 3: Experimental Analysis- Discussion of CSTR Results

During experimental analysis for the continuous stirred tank reactor experiment, ,monitoring of daily gas production from the digester 1,2,3 and 4 was concurrently carried out to avoid using **VFA/TIC** as a standalone monitoring parameter. Results of biogas production from the different digesters are shown in the figures 1,2 and brief discussion follows.

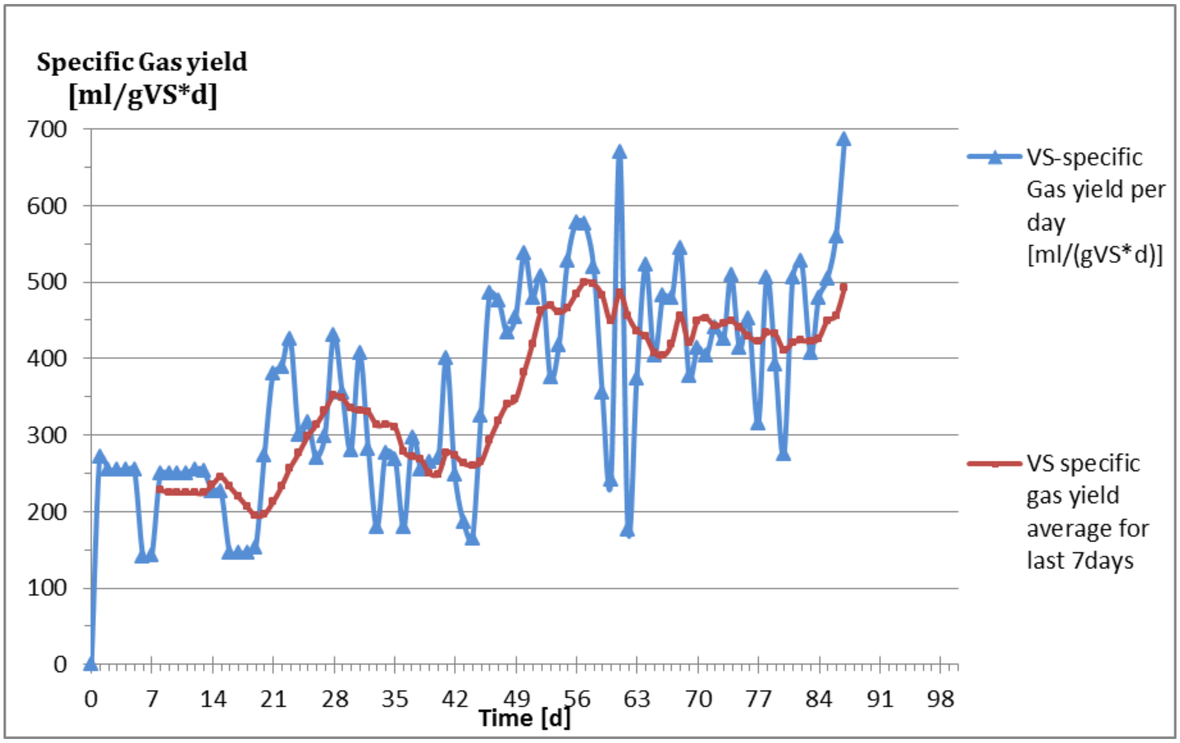

Figure 1: VS specific biogas gas yield for Digester 1(D1)

Source: Author

The overall trend of performance showed increase in biogas yield with increase of **OLR** from 0.5 to 2 **Kg VS/(m³*d).** The graph also showed fluctuation in daily biogas production. With the absence of **As** from **UCU, D1** was fed with **As** from Nordstrand from the 20th day onwards, this explains the low biogas yield as the digester stabilized before the yield increased again utill about the 28th day. The next drop in yield was after composition was of feed was changed around the 30th day. The sharp production of biogas noted on the 61st day was due to over feeding as a result of faulty feeding pump while the sharp drop on the 62nd day was associated with gas leakage from the gas bags.

It was also observed that an overall drop in gas yield from approximately **474ml/g VS*d** to about **445 ml/g VS*d** was noted when composition was initially changed from **As:Cd:Fw 20:30:50 to As: Cd:Fw 10:45:45.** However, the last phase of the experiment showed an increase in gas yield with the increase of **OLR** to **2 Kg VS/(m^3*d).** Taking into consideration that the **VFA/TIC** value at this stage was just 0.3, it implied that there was still possibility to increase feeding up to an OLR of **2.5 Kg VS/(m^3*d)** which was later considered**.** Finally, it was also interesting to note that when **As** from Nordstrand was used, the biogas composition showed lower values of **CH_4** (33.3%) and **CO_2** (25.5%) in comparison to when **As** from **UCU** was used i.e. **CH_4** (48-53%) and **CO_2** (38-45%). This was further explained by the fact the **As** from **UCU** had slightly more total solids (TS) 0.66-1.07% than **As** from Nordstrand i.e. 0.3-0.53%. Concurrently, the process monitoring of the specific gas produced daily in the course of the CSTR experiment for digester 2 (D2) is shown in Figure 2.

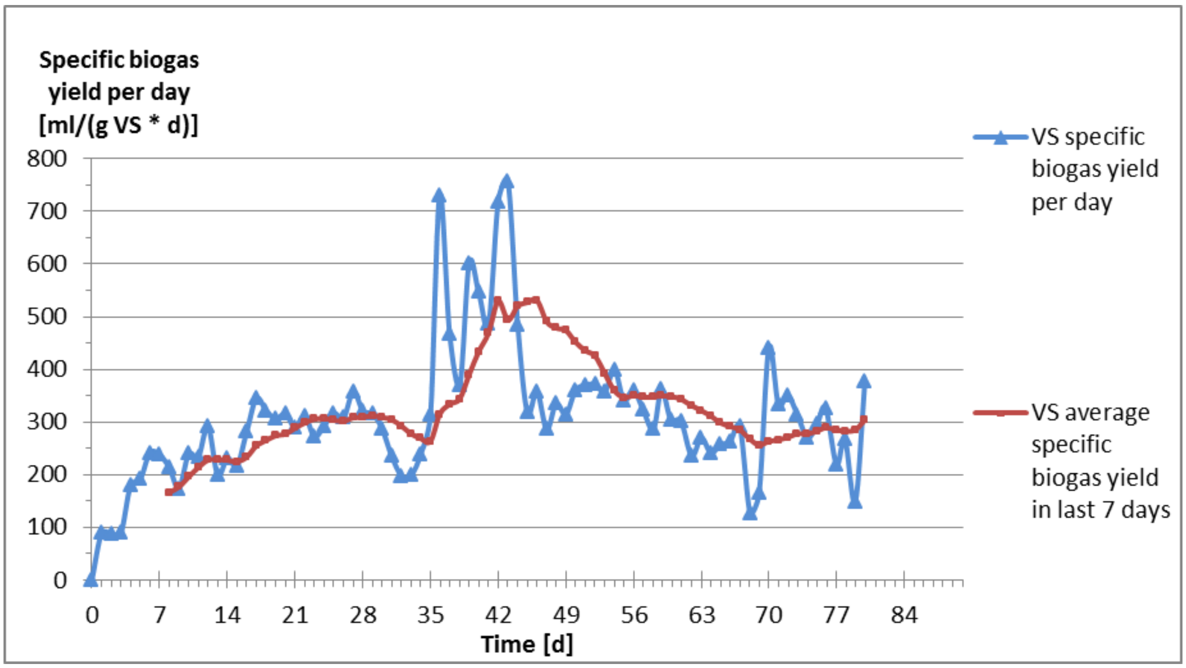

Figure 2: VS specific biogas gas yield for digester 2 (D2)
Source: Author

The results in figure 2 showed biogas yield increases with increase in **OLR** from **1, 1.5** and 2 **Kg VS/(m^3*d)** before a drop from about the 34th day was observed. The drop in biogas yield from about 731 **ml/g VS*d** to about **389 ml/g VS*d** was due to mixing of substrate composed of **Cd:Fw 40:60** with deionized water resulting in dilution. Later, an increase in the biogas yield to about 758 **ml/g VS*d** by the **43rd** day was observed**.** This increase was attributed to the increase in degradability caused by dilution of the substrate mixture **Cd:Fw 40:60** which particularly improves degradability of **Cd.** The presence of lignocellulosic materials in grass remains found in cow dung (Cd) hinders the rate of biodegradation of **Cd** at the initial stage (hydrolysis stage) (Khalid et al. 2011).

From **44th** day when the composition was changed to **Cd:Fw 70:30** and mixed with digestate from **D2** instead of water, simplifying the feeding process, the biogas yield dropped to about **360 ml/g VS*d**. This drop in biogas yield was explained by the fact the **Cd** with higher percentage in substrate mixture was not easily degradable during the hydrolysis stage in comparison to as **Fw.** Also the slight increase in biogas yield for **Cd:Fw 70:30** in comparison to **Os:Cd:Fw 50:20:30** at the same **OLR** was explained by the use of digestate to mix substrates for simplified feeding instead of water. Any remaining organic matter in the digestate is further degraded when digestate is recycled. Moreover the additionally active organisms in the digestate further enhance the digestion process in the digester once it is reused (VDI 2006).

In the latter stages of the experiment, substrate composition was changed to **Os:Cd:Fw 50:20:30** at **OLR 2 Kg VS/(m^3*d)** and was fed into the digester, a drop in biogas yield up to 285 **ml/g VS*d** was observed. This value was even lower than when the same substrate composition at an **OLR 1.5 Kg VS/(m^3*d)** was fed into the digester (from day 15-29) since the biogas yield then was **312ml/g VS*d.** The implication of these findings was that increase in **OLR from 1.5 to 2Kg VS/(m^3*d)** for same substrate composition was not recommended since gas yields dropped and the digester indicated strong loading as per the **VFA/TIC** value of **0.59**. Finally, change of substrate composition to **As:Cd:Fw 10:45:45** showed an increase in biogas yield of up to **377 ml/g VS*d** and optimal digester conditions shown by **VFA/TIC** value of **0.38**. Daily analysis of biogas composition with focus on **CH_4** and **CO_2** for **D2** was carried out and analysis showed **CH_4** accounted for **46-53%** while **CO_2** was in the range **28-52**%. Process monitoring of the specific gas produced in the course of the **CSTR** experiment for digester 3(D3) is shown in Figure **3.**

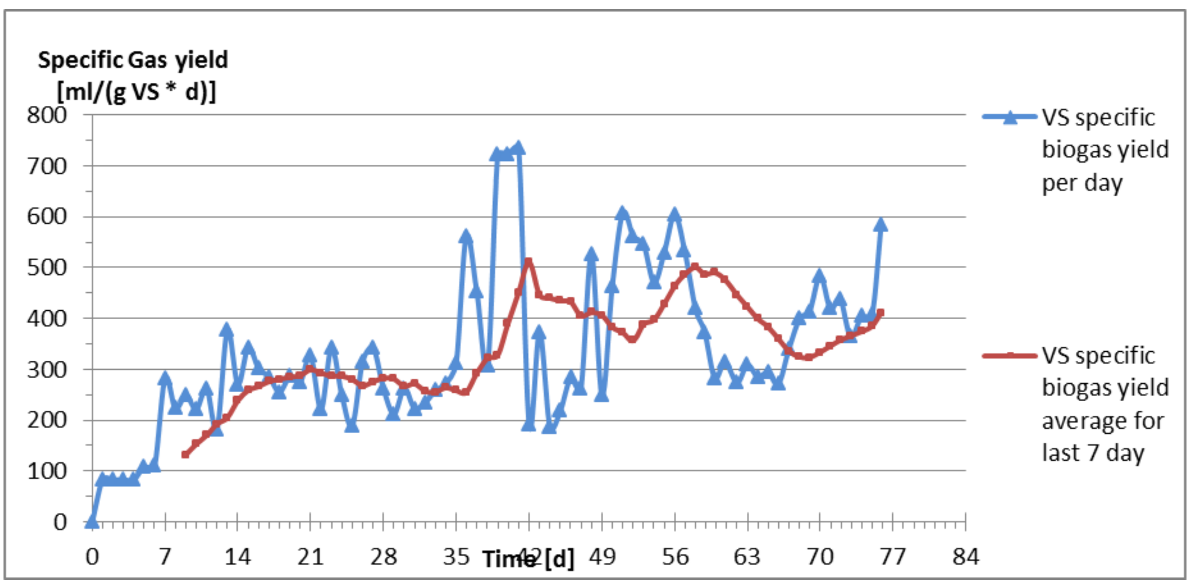

Figure 3: VS specific biogas gas yield for digester 3 (D3)
Source: Author

As shown in Figure 3 consecutive increase in biogas yield with increase of **OLR** from 1, **to** 2 **Kg VS/(m³*d)** before a drop up to **212 ml/g VS*d** about the **31st** day, later rising to **561ml/gVS*d** by the **37th** day was registered. This notable increase in biogas yield from 37th day onwards was attributed to the change in substrate composition from **O:Cd:Fw 33.3:33.3:33.3 to Cd:Fw 50:50**,reaching as high as **723 ml/g VS*d.** Taking into account that the substrate mixture in this duration was additionally mixed with deionized water, dilution took place allowing for easy degradation of **Cd** in **Cd:Fw 50:50 and** increasing overall biogas yield(refer to previous discussion)**.** The sharp drops noted were attributed to leakage of biogas from gas bags and this prompted replacement of gas bags. From **44th** day of the experiment when substrate composition was changed to **Cd:Fw 30:70** and mixed with digestate from **D3** instead of deionized water, the biogas yield began to rise again from **186ml/g VS*d,** reaching **604 ml/g VS*d**.

After another batch of **Os** sample was obtained from **UCU, D3** was again fed with **Os:Cd:Fw 33.3:33.3:33.3** at **OLR 2 Kg VS/(m³*d).** This resulted in a drop in biogas yield up to **283 ml/g VS*d** before rising again to about **336 ml/g VS*d** having run for only 10 days. With **VFA/TIC** value ranges, the results still showed that **D3** was underfed. Hence, increment of **OLR to 3 Kg VS/(m³*d)** for substrate composition **Os:Cd:Fw 33.3:33.3:33.3** could be considered. Change of substrate composition to **As:Cd:Fw 40:30:30** showed an increase in biogas yield of up to **583 ml/g VS*d** although the **VFA/TIC** value showed that **D3** was strongly fed. Daily analysis of biogas composition with focus on **CH_4** and **CO_2** for **D3** was carried out and the analysis showed that **CH_4** accounted for 46-58% while **CO_2** was in the range 28-52%. With reference to **CSTR** experiment for digester 4(D4), the process monitoring results are shown in Figure 4.

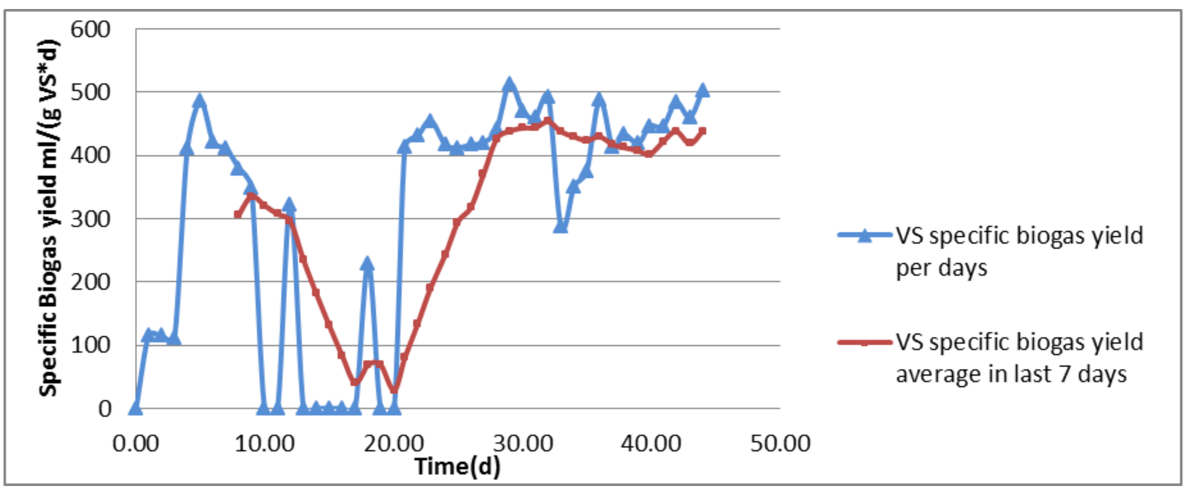

Figure 4: VS specific biogas yield for digester 4 (D4)
Source: Author

Intermittent gas production experienced at the initial stage of D4 operation resulted in intermittent production of biogas in the first two periods until about 21st day as shown in Figure 4 after the experiment was restarted. The main contributing factor to errors experienced at the initial stages of the experiment was that biogas leakage occurred mainly through the condensate and foam trap and to a small extent leakage through gas bags due to faulty valves. After trouble shooting and restarting the experiment, a relatively continuous gas production was observed from the 23rd day with a notable drop of up to **287 ml/g VS*d** on day 33rd day attributed to leakage from gas bags. Replacement of bags finally allowed for increment in biogas yield up to **503 ml/g VS*d** towards the end of experiment. Biogas composition for **D4** was **CH_4 (45-52%)** and **CO_2 (37-52%)**.

In summary, biogas yield in the digesters fluctuated with variation of substrate composition and it was also noted that after about 4 days of changing the substrate mixes, increasing or more stable biogas yield was noted. This observation concurs with suggestion from the (VDI 2006) that stabilisation of processes within the digester can be expected at least after a 14day period (VDI 2006). Despite fluctuations in biogas yield caused by leakages from gas bags, errors during running certain digesters i.e. **D4** and changing of substrate sources (As and Cd from Nordstrand, Germany instead of **UCU** substrate sources), **CH_4** and **CO_2** still constituted highest percentage in the biogas. Analysis of biogas composition from all digesters showed that the percentage contribution of **CH_4** ranged between **46-53%** while that of **CO_2** ranged between **29-52%.** In this state, the biogas generated could be used as cooking fuel although scrubbing is recommended. During the scrubbing process, biogas undergoes condensation, particulate removal, compression, cooling and drying thereby reducing impurities such as water vapor, other particles and hydrogen sulphide (H_2S) gas. The scrubbed biogas can then be efficiently utilised in burners and, or combined heat and power(CHP) units in case generation of electricity is considered (Al Seadi et al. 2008).

Appendix 4: Results for the Analysis of Sewage Sludge Sample from UCU Lagoon

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Web site: www.mia.go.ug

In any Correspondence on
this subject please
quote Ref.No. H017/2016

FOR GOD AND MY COUNTRY
THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DIRECTORATE OF GOVERNMENT ANALYTICAL LABORATORY
Plot No. 2 Lourdel Road
Wandegeya,
P.O.BOX 2174
Kampala - Uganda

10th May2016

MS AGUNYO MIRIA FRANCES
DEPARTMENT OF ENGINEERING
AND ENVIRONMENT, UCU

ANALYSIS REPORT:

SAMPLE DESCRIPTION	One sludge sample contained in a black polyethene bag.
ANALYSIS REQUESTED	Cd, Cu, Ni, Pb, Zn, K, total Nitrogen, and Phosphates
SOURCE OF SAMPLE	Uganda Christian University, UCU
SAMPLEDBY	Ms. Anguyo Miria Frances , Tel: 0782514800
DATE OF RECEIPT	25th April 2016
LAB SERIAL No.	WE 017/2016

This is to certify that the sludgesample has been analyzed with the following results:

PARAMETER	**MEAN- VALUES**	**EPA CEILING CONCENTRATION LIMITS FOR ALL BIOSOLIDS APPLIED TO LAND**
Cadmium [mg/Kg]	<0.001	**85**
Copper [mg/Kg]	7.5010	**4,300**
Nickel [mg/Kg]	<0.001	**420**
Lead [mg/Kg]	<0.001	**840**
Zinc [mg/Kg]	29.1073	**7,500**
Potassium [mg/Kg]	47.3979	-
Total Nitrogen [mg/Kg]	2.26	-
Phosphates [mg/Kg]	4.90	-

REMARKS:

- The sludge sample was found to conform to the limits specified in the EPAstandard.
- The results relate to the submitted sample and are reported as on received basis.

Thomas Mwanawakuno K.

Government Analyst

Page 1of1

" Go Scientific for a Safe and Just Society "

Source: National Government Laboratory, Uganda

Results of the Analysis of Wastewater Effluent from UCU Wastewater Treatment Plant

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI.
P.O.BOX 7053 KAMPALA.
E-mail: waterquality@nwsc.co.ug

CERTIFICATE OF ANALYSIS

CLIENT:UGANDA CHRISTIAN UNIVERSITY
Address: P.O.BOX 4 MUKONO
Tel: 0700650719
Email:
Date Sample Received: 11-Febuary--2016

Ref No:LS090/INV/2016/068
Sampled by: Client
Type of container: Plastic/Glass
Sample Source: Effluent
Date of Report : 16- March-2016

Table of Analytical Results

Parameters	Units	Wastewater	*National Standard for effluent discharge*
WS Sample Nr	--	**K387/16/C/B**	
Electrical Conductivity	μ/Scm	421	***1500***
Alkalinity	mg/L	300	***800***
Bio-Chemical Oxygen Demand (BOD)	mg/L	**75**	***50***
Sulphate	mg/L	7	***500***
COD	mg/L	**150**	***100***
Ortho-phosphate	mg/L	0.089	***5.0***
Total Nitrogen	mg/L	6.53	***20.0***
Total Phosphorous	mg/L	0.08	***10.0***
Nitrate	mg/L	0.11	***10.0***
Bacteriological: Faecal Coliforms	CFU/100mL	0	***5,000***

Remarks:
The effluent sample showed good Physical-chemical and bacteriological characteristics with the exception of BOD, and COD as compared to the National standard for effluent discharge.

ANALYSED BY: Robinah Muheirwe and Hawa Nakitende

AUTHORISED BY: ....**MANAGER, Central Laboratory Services**

APPROVED BY: ....**SENIOR MANAGER, Water Quality Management Department**

NB: The NWSC certificate of analysis by no means constitutes a permit to any person or company undertaking to conduct business

NATIONAL WATER AND SEWERAGE CORPORATION
EXTERNAL SERVICES
P. O. Box 7053, Kampala, Uganda
Tel: +256 414 315 111/107
Email: external.services@nwsc.co.ug

Source: National Water and Sewerage Corporation Laboratory

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI.
P.O.BOX 7053 KAMPALA.
E-mail: waterquality@nwsc.co.ug

CERTIFICATE OF ANALYSIS

CLIENT: UGANDA CHRISTIAN UNIVERSITY

Address: P.O.BOX 4 MUKONO

Tel: 0700650719

Email:

Date Sample Received: 09 th - ~~Febuary~~ March -2016

Ref No: LS090/INV/2016/068

Sampled by: Client

Type of container: Plastic/Glass

Sample Source: Effluent

Date of Report : 16- March-2016

Table of Analytical Results

Parameters	Units	Wastewater	*National Standard for effluent discharge*
WS Sample Nr	--	**K798/16/C/B**	
Electrical Conductivity	µ/Scm	714	***1500***
Alkalinity	mg/L	200	***800***
Bio-Chemical Oxygen Demand (BOD)	mg/L	4.7	***50***
Sulphate	mg/L	28	***500***
COD	mg/L	56	***100***
Ortho-phosphate	mg/L	0.693	***5.0***
Total Nitrogen	mg/L	16	***20.0***
Total Phosphorous	mg/L	0.79	***10.0***
Nitrate	mg/L	0.7	***10.0***
Bacteriological: Faecal Coliforms	CFU/100mL	1000	***5,000***

Remarks:
The effluent sample showed good Physical-chemical and bacteriological characteristics as compared to the National standard for effluent discharge.

ANALYSED BY: Robinah Muheirwe and Hawa Nakitende

AUTHORISED BY: ....**MANAGER, Central Laboratory Services**

APPROVED BY: ....**SENIOR MANAGER, Water Quality Management Department**

NB: The NWSC certificate of analysis by no means constitutes a permit to any person or company undertaking to conduct business

Appendix 5: UCU Stakeholder Survey Authorisation and Questionnaire

UGANDA CHRISTIAN UNIVERSITY
A Centre of Excellence in the Heart of Africa

November 11, 2016

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

INTRODUCING AGUNYO MIRIA FRANCES

Greetings in the precious name of our Lord Jesus Christ!

I wish to introduce to you, the above named person, who is visiting PhD research student from **Europa Universität Flensburg, Germany.**

She is conducting research at Uganda Christian University entitled **"Feasibility of an integrated sanitation system for Uganda Christian University -Mukono".**

She has been here before from March - May 2015 and April 2016 to August 2016. She intends to be here between April and end of May 2016 for the third part of her research which includes a survey on the perception and opinions of sanitation system at Uganda Christian University.

All concerned offices and officers are requested to offer her all possible support.

Yours sincerely,

UGANDA CHRISTIAN UNIVERSITY
11 NOV 2016
DEAN

Peter Ubomba-Jaswa, PhD
Head, Research, Publications and Grants
School of Research & Postgraduate Studies
Email: pubomba-jaswa@ucu.ac.ug
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P. O. Box 4, Mukono, Uganda Tel: +256 (0) 31 235 0800 Fax: +256 (0) 41 429 0800 Email: ucu@ucu.ac.ug Web: www.ucu.ac.ug

Founded by the Province of the Church of Uganda. Chartered by the Government of Uganda

UCU Survey Questionnaire

Name: Agunyo M.F
University: Europa University Flensburg, Germany

Dear Respondent

This survey is part of Ph.D. research to explore the *feasibility of an integrated sanitation system at Uganda Christian University- Mukono*. The proposed integrated sanitation system considers combined management of organic waste generated mainly from the University and possibly neighboring areas of Mukono with the twofold objective; improved sanitation from waste management and resource recovery inform of energy mainly from biogas and nutrients from digestate as organic fertilizer. The University currently has a sanitation system which manages different waste streams separately. Hence, the purpose of this survey is to obtain an understanding about your perception and opinions of the existing and proposed sanitation systems as a stakeholder within the University. We recognize the value of your time, and sincerely appreciate your efforts on our behalf. Individual responses are anonymous and all obtained data will be held in confidence. Participation in the survey is voluntary and thankyou again for your time.

Part 1: General Information

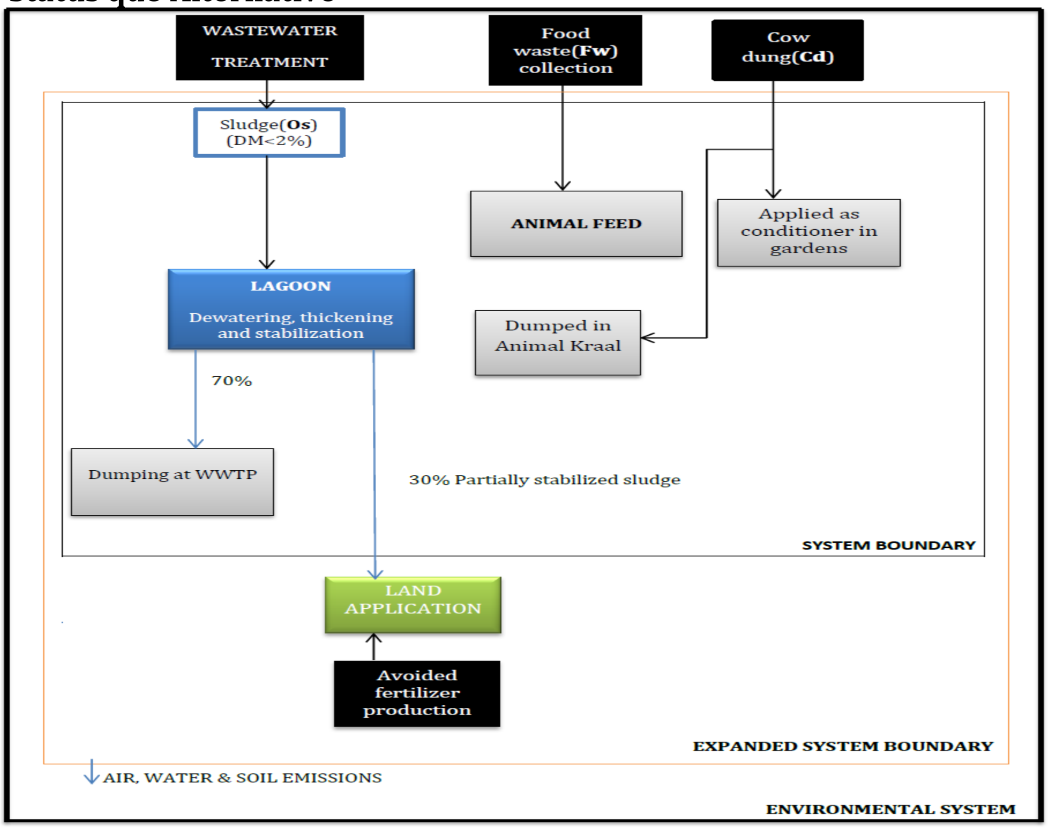
1. **Please indicate your occupation**
   Student ☐ University Employee ☐ Others specify ☐
2. For University employees, please indicate position held.

3. Please indicate your sex Female ☐ Male ☐
4. Briefly mention how the following organic waste is managed at the University.

   Human waste
   Other organic waste (kitchen/food, compound cuttings, etc.)

Part 2: Six sanitation system scenarios for management of organic waste including the current mode of operation at the University are considered, please answer the following questions as you deem fit.

Status quo Alternative



Source: Author

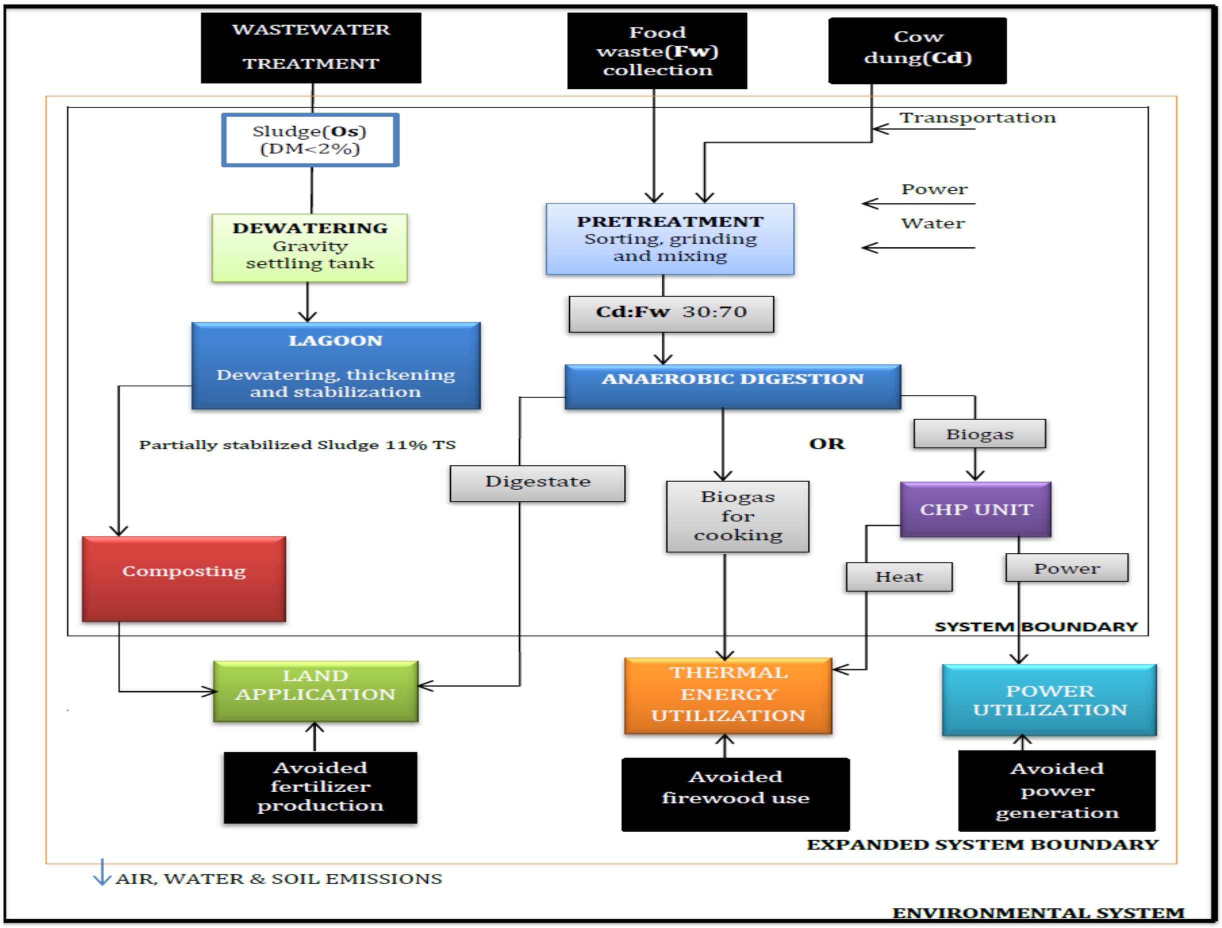
5. What is your opinion about the current organic waste management measures at the University?

   Sufficient ☐ Insufficient ☐ could be improved ☐

6. Please give reasons for your answer in **Qn 5** above?

7. In case of improvement of the sanitation system above, what measures would you recommend?

COMPAD Alternative



Key by- products include; compost and digestate as organic fertilizer, biogas for cooking or co-generation of heat and electricity.

8. Would you be willing to utilise compost from sewage sludge? Yes ☐ No ☐

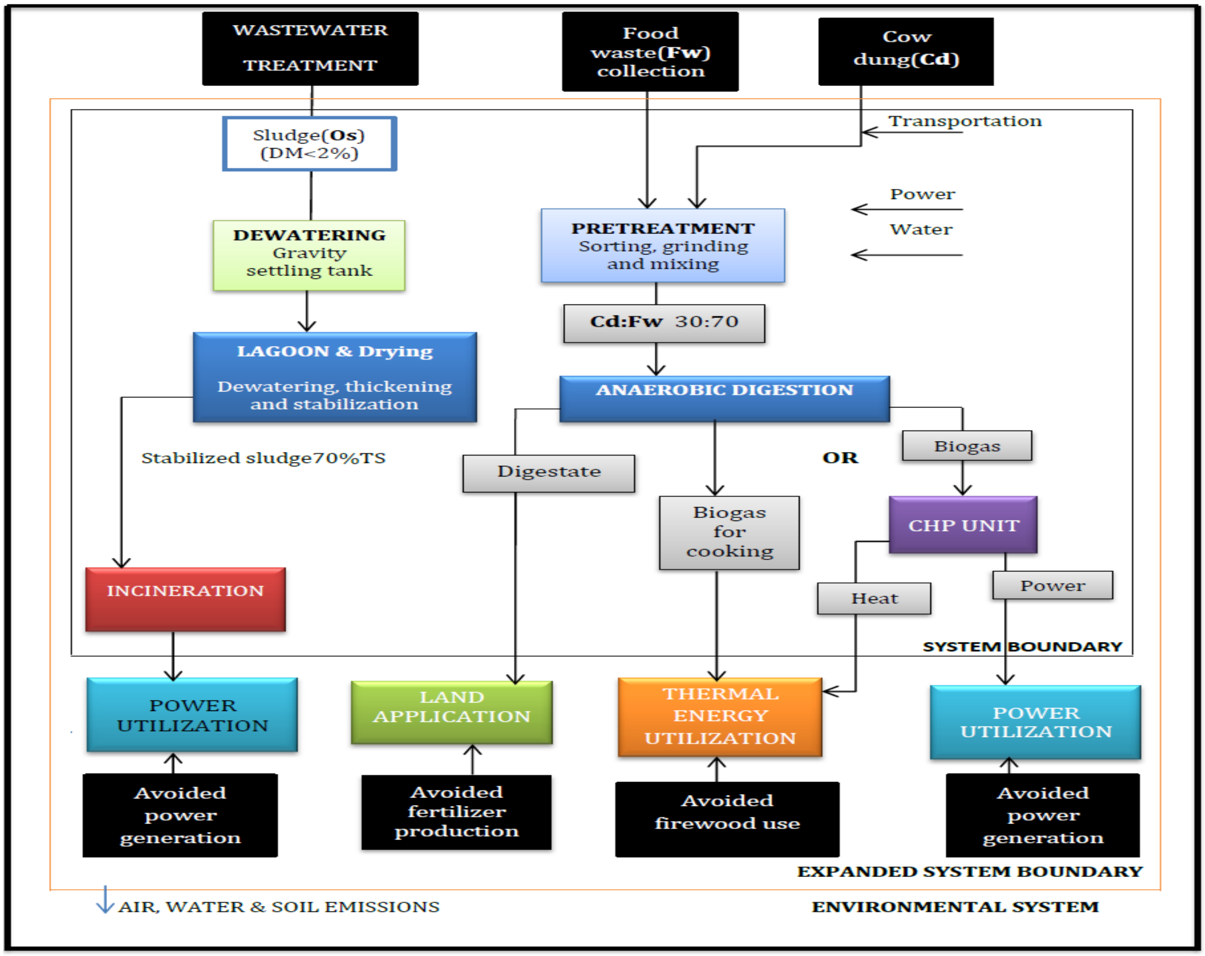
9. Would you be willing to utilise the digestate generated from the anaerobic digestion of cow dung and food waste as organic fertilizer? Yes ☐ No ☐

10. What is your opinion regarding utilization of biogas generated from **COMPAD scenario** for cooking purposes?

Agree ☐ Not certain ☐ Disagree ☐

11. Please give reasons for each of your answers in questions 8, 9 and 10.

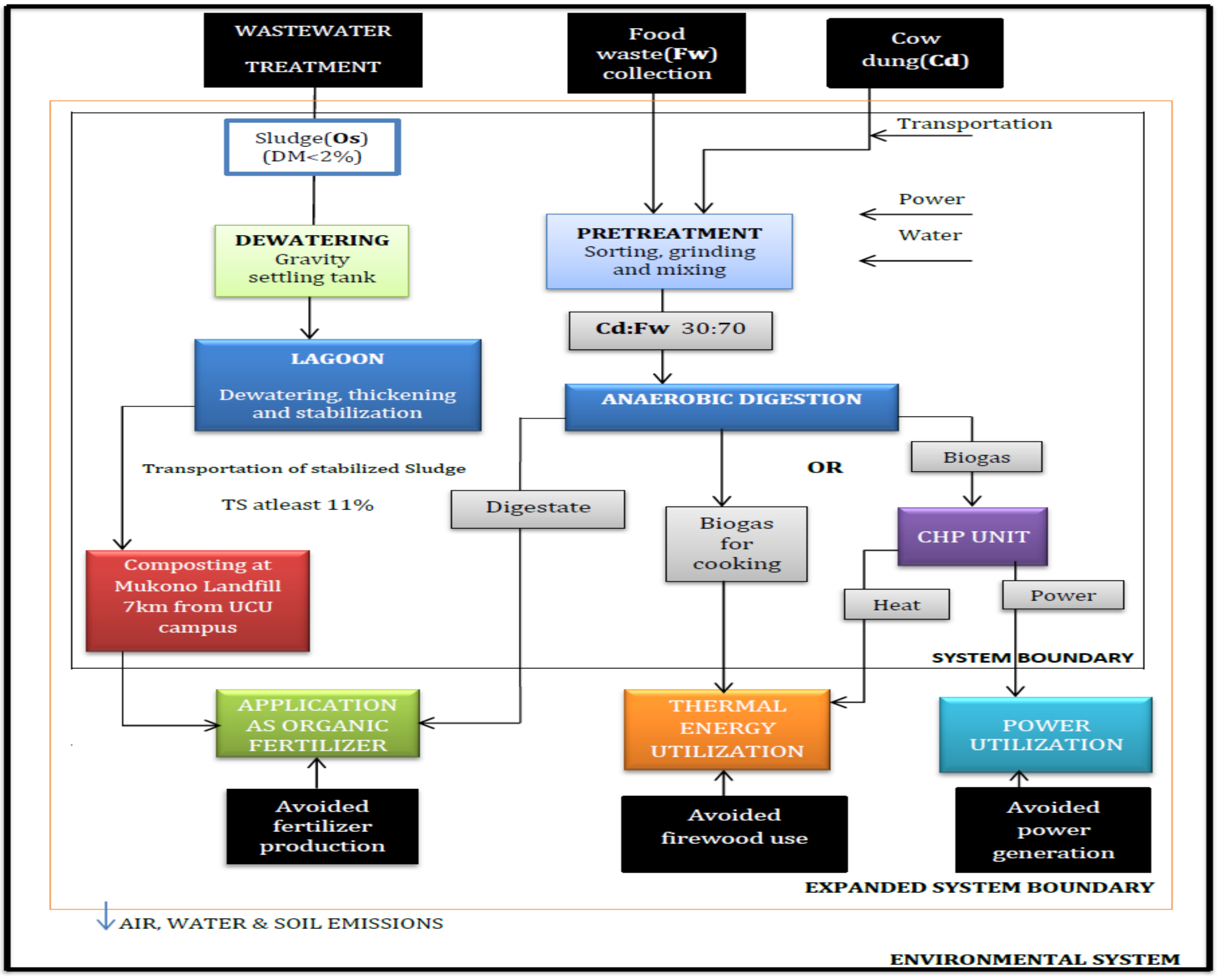
INCAD Alternative



Main by-products; digestate as organic fertilizer, biogas for cooking or co-generation of heat and electricity from Combined Heat and Power (CHP) unit and incineration process.

12. What is your opinion regarding incineration of dried sewage sludge?

COMPAD LF Alternative



Key by- products include; compost and digestate as organic fertilizer, biogas for cooking or co-generation of heat and electricity.

Which of the composting system scenarios would you prefer?

- COMPAD-(Composting of stabilised sewage sludge at **UCU**)

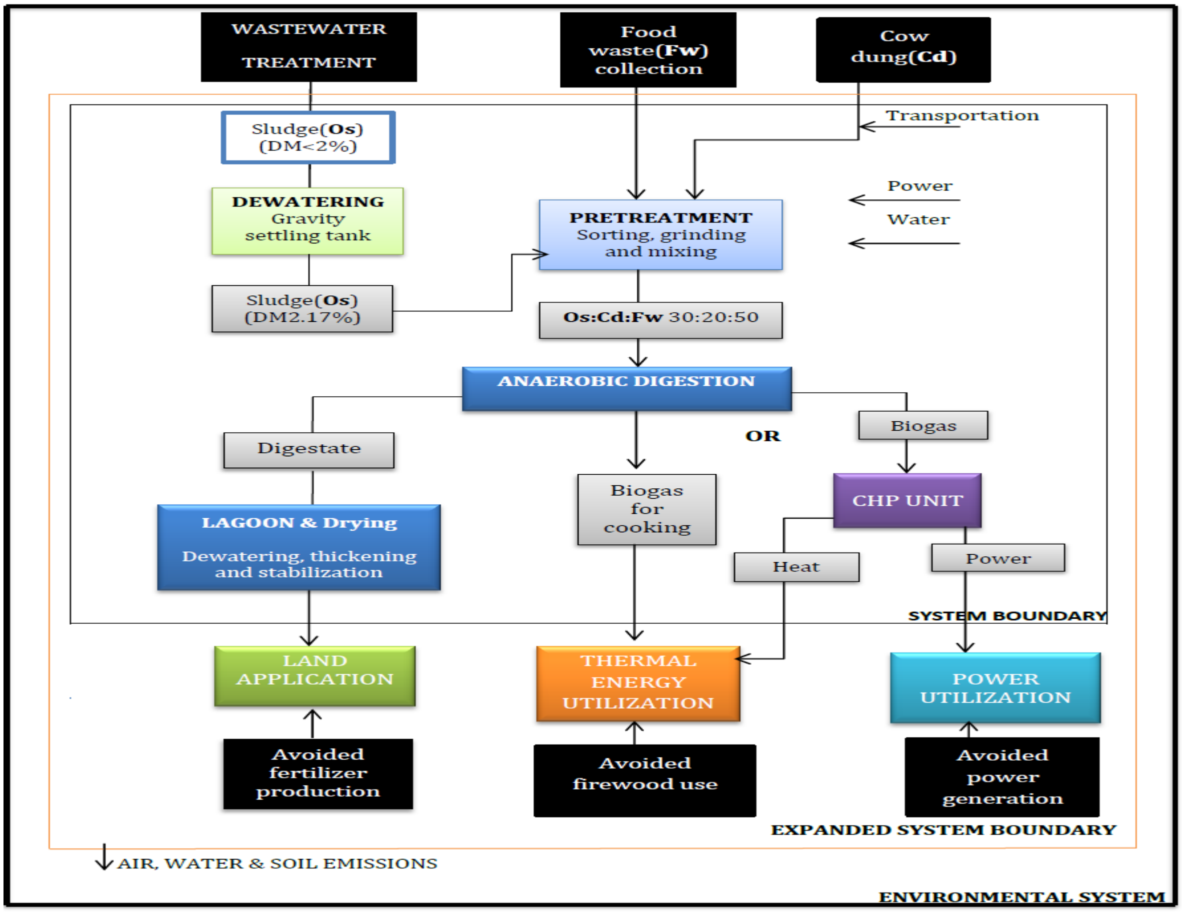
  Yes ☐ No ☐

- COMPAD LF-(Composting of stabilised sewage sludge at Mukono Landfill)

  Yes ☐ No ☐

Please give reasons for the choice of composting scenario.

INTEG 1 Alternative



By products of system; digestate as organic fertilizer, biogas for cooking or cogeneration of electricity and heat from **CHP**.

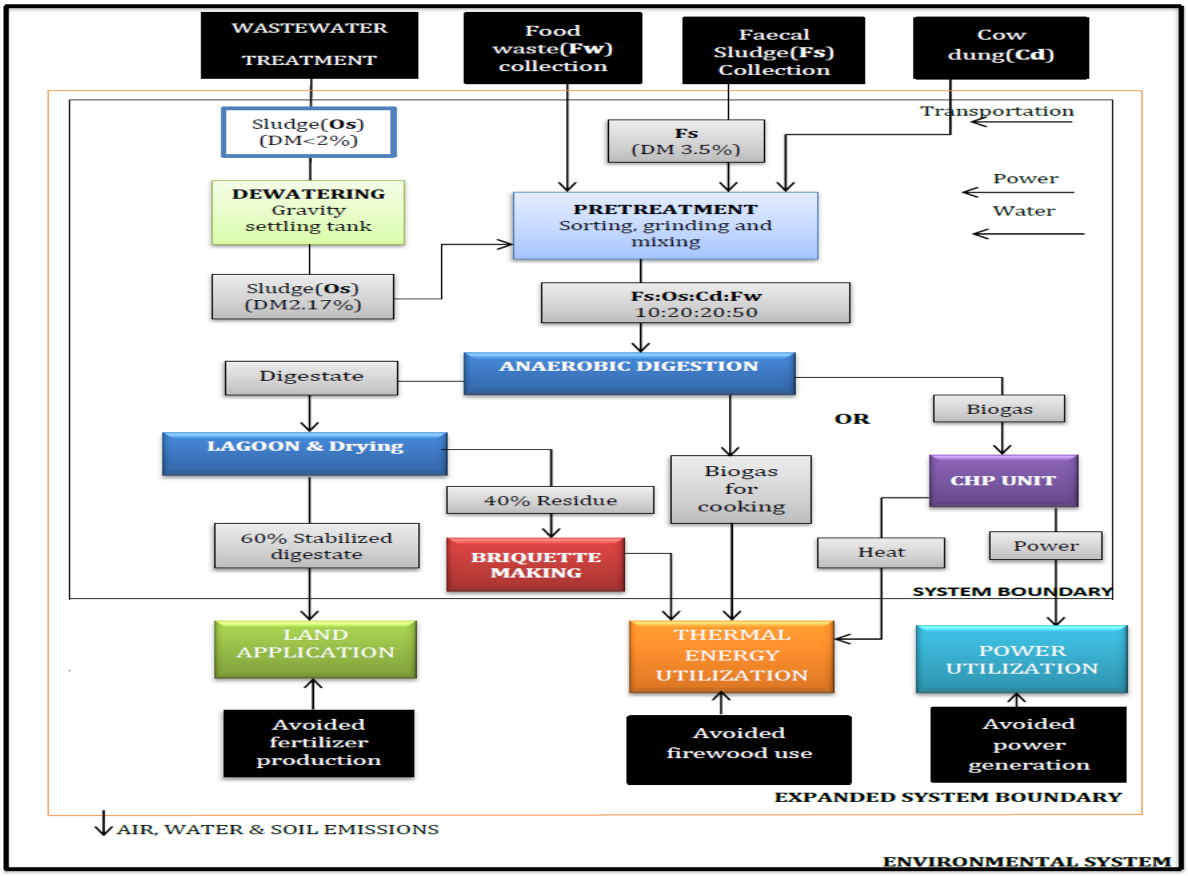
13. Would you be willing to utilise digestate (from sewage sludge, cow dung, food waste) generated as organic fertilizer? Yes ☐ No ☐

14. What is your opinion regarding utilisation of biogas generated from **INTEG 1 scenario** for cooking purposes?

Agree ☐ Not certain ☐ Disagree ☐

15. Please give reasons for each of your answers in questions 13 & 14**.**

INTEG 2 Alternative



By-products of system; digestate as fertilizer, briquettes from digestate as solid fuels, biogas for cooking or cogeneration of electricity and heat from CHP unit.

16. Would you be willing to utilise digestate (sewage+faecal sludge, cow dung, food waste) generated as organic fertilizer? Yes ☐ No ☐

17. Would you be willing to utilise briquettes produced from the digestate generated from **INTEG 2 scenario** for cooking purposes? Yes ☐ No ☐

18. What is your opinion regarding utilisation of biogas generated from **INTEG2 scenario** for cooking purposes?

Agree ☐ Not certain ☐ Disagree ☐

19. Please give reasons for each of your answers in question 16, 17 and 18.

20. For all biogas generating sanitation systems scenarios, which is your preferred mode of biogas utilisation?

- Biogas for cooking Yes ☐ No ☐
- Biogas for cogeneration of heat and electricity Yes ☐ No ☐

21. Please give reasons for your answer to question 20.

22. On a scale of **1-6**, please rate the noise and odour nuisance anticipated from the following sanitation system options. (**1 represents lowest level of noise or odor and 6 represents the highest level of noise or odour respectively)**

- **Status quo** consists(wastewater treatment**+** partial stabilization of sewage sludge in the lagoon at UCU)

  Noise nuisance ☐ Odour nuisance ☐

- **COMPAD** (composting of sewage sludge at UCU**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

  Noise nuisance ☐ Odour nuisance ☐

- **COMPAD LF**(composting of sewage sludge at Mukono landfill**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

  Noise nuisance ☐ Odour nuisance ☐

- **INCAD(**Incineration of sewage sludge at UCU**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

  Noise nuisance ☐ Odour nuisance ☐

- **INTEG 1(**production of biogas and fertilizer from sewage sludge**+** cow dung **+** food waste at UCU)

Noise nuisance ☐ Odour nuisance ☐

- **INTEG 2**(production of biogas and fertilizer from sewage sludge**+** faecal sludge**+**cow dung**+**food waste and production of briquettes from digestate mixture at UCU)

Noise nuisance ☐ Odour nuisance ☐

23. On a scale of **1-6**, please rank the six sanitation system options according to level of convenience and acceptability. (**1 represents lowest level of convenience or acceptability and 6 the highest level of convenience or acceptability respectively**)

- **Status quo** consists(wastewater treatment**+** partial stabilisation of sewage sludge in the lagoon in UCU)

Convenience ☐ Acceptability ☐

- **COMPAD** (composting of sewage sludge at UCU**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

Convenience ☐ Acceptability ☐

- **COMPAD LF**(composting of sewage sludge at Mukono landfill**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

Convenience ☐ Acceptability ☐

- **INCAD(**Incineration of sewage sludge at UCU**+** production of biogas and organic fertilizer from food waste and cow dung at UCU)

Convenience ☐ Acceptability ☐

- **INTEG 1(**production of biogas and fertilizer from sewage sludge**+** cow dung **+** food waste at UCU)

Convenience ☐ Acceptability ☐

- **INTEG 2**(production of biogas and fertilizer from sewage sludge**+** faecal sludge**+**cow dung**+**food waste and production of briquettes from digestate mixture at UCU)

Convenience ☐ Acceptability ☐

Thank you for your time

Appendix 6: Sustainability Assessment: Elicitation of information for MCDA from Stakeholders

Questionnaire for Evaluation of Sanitation System Alternatives Proposed for UCU

Introduction

According to the 6 year strategic plan, **Uganda Christian University (UCU)** in Mukono is interested ensuring sustainable environment through utilisation of organic waste generated from the University for energy generation in form biogas. In so doing, the University is additionally interested in switching from her dependence on firewood for cooking purposes to cleaner energy from biogas (1). Thus, in an attempt to achieve these objectives, this research proposes to explore the ***feasibility of an integrated sanitation system for the University***. The proposed integrated sanitation system would be a result of improving or upgrading the existing sanitation system to consider co-management of various organic waste streams generated from the University and neighboring areas of Mukono. The main organic waste streams considered are food waste, cow dung, sewage sludge from **UCU**, and possibly faecal sludge from neighboring areas in Mukono. With reference to the two fold objective of sanitation management and energy generation, anaerobic digestion process is one of the key components of the proposed sanitation system.

Sanitation System Scenario Design

To accommodate variable routes of achieving the University`s two fold objectives, five sanitation system scenarios were designed. The basis for designing the scenarios included informant interviews with key personnel at the University, Mukono municipality officials, observation of existing waste management measures at the University and relevant literature review. Thus, with reference to the information obtained, screening of sanitation systems scenarios was done and five scenarios in addition to the current sanitation system were considered. For each of the six sanitation system scenarios, anaerobic digestion technology was included a key component in combination with other processes like incineration, composting, solar drying and production of solid fuel in form of briquettes. To inform the decision on possible improvement and or selection of a sanitation system for the University, sustainability assessment of designed scenarios will be carried out using multi criteria decision analysis **(MCDA**). The methodology which basically guides complex decision making has atleast eight stages including evaluation/scoring of performance for suggested alternatives/scenarios (Belton, and Stewart 2002) which is the purpose of this questionnaire.

Assessment of Sanitation System Alternatives

In carrying out the sustainability assessment of the sanitation system scenario, four main aspects which include environment and natural resources, economic, technical and socio-cultural are considered. Each of the aspects is further defined by criteria for which specific indicators are used as parameters for measurement/assessment.

Selection of criteria and indicators was carried out with reference to available literature on sustainability assessment of sanitation systems further supported by stakeholder contribution with reference to the **UCU** context (Lennartsson 2009; Ashley et al. 2003; Elvas, Sy 2008; van Buuren 2010). This questionnaire specifically attempts to elicit stakeholder evaluation of the six sanitation system scenarios i.e. including the existing system using selected indicators. Sustainability assessment of the sanitation system scenarios will be carried out with respect to. However, before evaluation of the scenarios can be carried out, a brief definition of the sanitation system scenarios follows.

System Alternative Description.
Status Quo scenario basically shows the current sanitation system at the University where sewage sludge from activated wastewater treatment plant (**WWTP)** is directed to a gravity settling tank where dewatering takes place. The partially dewatered sewage sludge is then directed to the lagoons where stabilisation takes place. After a duration of 1 year, 30% stabilised sludge is utilised as conditioner at University sports field and by interested local farmers as fertilizer. Meanwhile, the final disposal of residual stabilized sludge (70%) is left in the lagoons over a longer duration of time posing a major disposal challenge. Alternately, other organic waste management routes include use of food waste (**Fw**) from the University kitchen as animal feed by locals neighboring the University. Cow dung (**Cd)** from **UCU** holdings farm located at Ntawo about 3.5 km from the University campus is used as conditioner in neighbouring gardens by local farmers or dumped in animal Kraal.

COMPAD scenario considers further treatment of the lagoon stabilized sewage sludge by composting it with other organic waste like compound cuttings/trimming, shavings from University carpentry etc. Composting would be accomplished within the University premises and compost sold to interested persons. In addition, anaerobic co-digestion of cow dung (**Cd)** and food waste **(Fw)** at composition ratio **30:70** respectively is considered. The biogas generated can be utilized directly for cooking purposes or used for cogeneration of electricity and heat from a combined heat and power (**CHP**) unit. The generated heat would be used for heating water later utilised for cooking purposes and maintaining mesophilic temperatures in digester especially during rainy season. Also, the digestate produced from the anaerobic digester would be utilized as organic fertilizer.

COMPAD LF scenario is similar to **COMPAD** (anaerobic co-digestion of cow dung & food waste) although, **COMPAD LF** considers composting of the lagoon stabilized sewage sludge at Mukono landfill located about 7km from University campus (Aryagaruka, and Otim 2006). The landfill has an already operational composting plant. Thus, after fulfilling any necessary requirements and or reaching an understanding with Mukono Municipality authorities, the University would transport the lagoon stabilised sludge to Mukono landfill for composting**.**

INCAD scenario is similar to the **COMPAD** scenario (anaerobic co-digestion of cow dung & food waste) with the exception of incineration of the lagoon stabilized sewage sludge instead of composting. However, prior to incineration, the stabilized sewage sludge would be further dried in solar drier to attain a total solid content of atleast 50%. Thereafter, the dried sewage sludge would be co-incinerated with other waste at the University proposed medical incineration unit.

INTEG 1 scenario considers anaerobic co-digestion of sewage sludge, food waste and cow dung at a composition ratio of **30:50:20** respectively. Similar to **COMPAD** scenario, the generated biogas can either be used directly for cooking purposes or cogeneration of electricity and heat. While, digestate would be directed to the lagoon for stabilization before it can be solar dried enhancing pathogen reduction and portability before it is used as fertilizer.

INTEG 2 scenario additionally considers anaerobic co-digestion of faecal sludge, sewage sludge, cow dung, and food waste in the composition ratio **10:20:50:20** respectively. Handling of the generated biogas is accomplished in a similar manner to **INTEG 1**.
While, for the digestate, in addition to lagoon stabilization and solar drying, 40% of the dried digestate is used for making briquettes later used for cooking and the remaining 60% stabilised digestate utilized as organic fertilizer.

Selected Indicators
As already mentioned, each of the aspects is further defined by criteria for which specific indicators are used as parameters for measurement/assessment. The measurement of the indicators result in qualitative judgment or a quantitative performance score. The current task focuses on the qualitative judgment of sanitation system scenarios with reference to selected indicators. The indicators grouped under criteria are briefly described with a scale of assessment suggested as shown in Table 3.

Evaluation of Sanitation System Alternatives
Table 3 shows the selected indicators for which the six sanitation system scenarios are to be evaluated. Please indicate the respective response for the specific scenarios in the provided spaces in the Table. With reference to the scales suggested e.g. low, medium and high. Reference can be made to **Table 3** for brief description of the indicators and suggested scales.

Table 3: Description of selected indicators

Indicator	Units/scale	Scale description	Description
Robustness Index			
Sensitivity of sanitation system to shock loads	Low sensitivity=10 Moderate sensitivity=5 High sensitivity=0	***Low sensitivity*** *overall impact of shock loads on sanitation system performance is negligible.* ***Moderate sensitivity*** *impact of shock loads on performance of sanitation system is moderate.* ***High sensitivity*** *impact on sanitation system performance due to impact of shock loads is significant.*	Effect on sanitation system performance due to shock loads caused by absence or fluctuation of electricity, organic waste as inputs, variation in operation parameters (temperature, ph.) and irregular maintenance.
Risk of sanitation system failure	Low risk;=10 Medium=5 High=0	***Low risk*** *possibility of sanitation system failure is negligible.* ***Medium risk*** *occurs when failure in certain components of sanitation system does not result in failure of entire system.*	Failure of sanitation system to adequately manage/treat organic waste. Failure could be due to variation of operation parameters (temperature, ph.), impacts due climatic conditions among others.

		High risk *occurs when variation in operation parameter and climatic conditions can result in failure of entire system.*	
Complexity of sanitation system			
Possibility to utilize locally available material and labor for construction of sanitation system	Low =0 Medium= 5 High=10	***Low****; External expertise and imported material required for construction/installation of entire sanitation system.* ***Medium****; A combination of locally available skilled labor, external expertise, locally available and imported material required for construction/installation of sanitation system.* ***High****; Construction/installation of entire sanitation system can*	Construction of sanitation system achieved using locally available material and skilled labor/expertise.

		be accomplished using locally available material and skilled labor.	
Possibility to utilize locally available labor for operation & maintenance of sanitation system	Low=0 Medium=5 High=10	***Low***; *External expertise required for operation & maintenance of entire sanitation system.* ***Medium***; *A combination of locally available skilled labor and external expertise required for operation and maintenance of the sanitation system.* ***High***; *locally available skilled labor/expertise sufficient for the operation and maintenance of the entire sanitation system.*	Operation and maintenance of sanitation system can be achieved by locally available skilled expertise.
Flexibility			

Adaptability of sanitation system to new conditions and requirements	Low= 0 Moderate=5 High=10	***Low;*** *adaptation of sanitation system cannot be achieved without major modifications.* ***Moderate****; adaptation of sanitation system can be achieved with minor modifications.* ***High;*** *adaptation of entire sanitation system can be easily achieved.*	The ease with which the sanitation system can adapt to new conditions and requirements i.e. changes in organic waste composition and quantities, climatic conditions, system upgrade among others.
Acceptability			
Perception	Negative=0 Reluctant = 5 Positive=10	***Negative*** *feelings towards handling/management of organic waste streams and utilization of byproducts due to beliefs.* ***Reluctant or*** *mixed feelings towards handling/management waste streams and utilization of byproducts influenced by beliefs and anticipated benefits.*	General feeling towards the sanitation system due to handling/management organic waste and utilization of byproducts i.e. organic fertilizer, solid fuels and biogas.

		Positive *feelings towards sanitation system associated with anticipated benefits.*	
Convenience	Low=0 Moderate=5 High =10		Level of comfort experienced by users of sanitation system. This may be affected by impacts like noise, odor from transporting and handling of organic waste, alteration of aesthetics and safety concerns to University community.

Table 4: Evaluation of sanitation system alternatives based on selected indicators

Indicators	Status Quo	COMPAD	COMPAD LF	INCAD	INTEG 1	INTEG 2
Sensitivity of sanitation system to shock loads **Scale(Low, Moderate, High)**						
Risk of sanitation system failure **Scale(Low, Medium, High)**						
Possibility to utilize locally available material and labor for construction of sanitation system **Scale(Low, Medium, High)**						
Possibility to utilize locally available labor for operation & maintenance of sanitation system **Scale(Low, Medium, High)**						
Adaptability of sanitation system to new conditions and requirements.						

Scale(Poor, Moderate, High)						
Perception **Scale(Negative, Reluctant, Positive)**						
Convenience **Scale(Low, Moderate, High)**						

Questionnaire Eliciting Weights for Criteria and Indicators

In an attempt to inform the decision on possible improvement and or selection of a sanitation system for Uganda Christian University (**UCU**), sustainability assessment of sanitation system scenarios is carried out using multi criteria decision analysis (MCDA). Defined as a mathematical method that can be used for selection of the best possible alternative or ranking of options, MCDA utilizes a decision matrix of criteria and performance scores to provide a systematic analytical approach to integrate risk levels, uncertainty, and valuation (DCLG 2009; Belton, and Stewart 2002) MCDA has atleast six stages which include identification of problems, formulation of objectives, criteria and indicators, identification/formation of alternatives, description of performance for each alternative, weighting and evaluating scores of criteria for each alternative, examining results and conducting a sensitivity analysis. This summary paper particularly tackles assigning of weights to sub-criteria (also referred to as indicators) selected by stakeholders for the evaluation of suggested sanitation system scenarios.

In carrying out the sustainability assessment of the sanitation system scenarios, four main aspects which include environment and natural resources, economic, technical and socio-cultural are considered. Each of these aspects is further defined by criteria for which specific sub-criteria (indicators) are used as parameters for measurement/assessment.

Weighting Method

Most often, not all criteria and or indicators are considered to have the same level of importance when evaluation of alternatives or sanitation system scenarios for this research is considered (Belton, and Stewart 2002). The variance in level of importance a stakeholder/expert may attach to different criteria or indicators is referred to as relative importance. The relative importance attached to criteria or indicators can be reflected by weighting. The weight assigned to the particular criterion is a scaling factor which relates the score of a particular criterion to scores of other criteria. As already mentioned, in this research the four sustainability aspects are further defined by criteria and indicators. Certain criteria are defined by more than one indicator forming a family while other criteria are defined by a single indicator. As such, the weights will be assigned to each of the indicators. For criteria consisting more than one indicator (family), each indicator is assigned a weight representing it`s relative importance with reference to other indicators within the family.

Assigning of weights is done with reference to the swing weighting method which basically considers allocating weights from worst to best value for each indicator. As such, the criterion assigned the highest weight is that one which the swing gives the greatest increase in overall value; this process is repeated on the remaining set of criteria until the order of benefit resulting from a swing from worst to best on each criterion has been determined and this defines a ranking of the criteria weights. For instance, if a swing from worst to best on the most highly weighted criterion is assigned a value of 100, the relative value of a swing from worst to best on the second ranked criterion could be 60.

In this research, a value of **100** is attached to the best value while **0** represents the worst value. Hence, using the swing method, weights assigned to each of the indicators and criteria within a family, factoring in the relative importance of the criterion or indicator within a family. Meanwhile for criteria defined by a single indicator, the weight assigned will be based on the overall importance attached to the indicator by the stakeholder/expert (Belton, and Stewart 2002).

Assigning of weights to indicators

Therefore, based on the brief discussion on weighting methodology in the previous section, i.e worst value represented by **0** and best value by **100**, please assign weights to the respective indicators based on relative importance in spaces provided in Table 5.

Table 5: Assigning of weights to Indicators

Aspects	Criteria	Indicators	Weight
Environment & Natrual resources	Resource Utilisation	Land requirement for sanitation system development (m^2)	
	Impact on the Environment	Global Warming Potential (kg CO_2eq/year)	
		Eutrophication Potential (kg PO_4^{-3} eq/year)	
		Human Toxicity Potential (kg DCB eq/year)	
	Resource recovery	Energy recovered (kWh/year)	
		Nutrients recovered (kg/year)	
		Water recovered (l/year)	
Economic	Economic desirability	Life cycle costs (UGX/year)	
		Benefit cost ratio	
Technical Functionality	Complexity of System	Possibility to utilise local material and skilled labour for construction of system	

		Possibility to utilise locally available skilled labour for operation and maintenance of system	
	Robustness	Risk of sanitation system failure	
		Sensitivity of sanitation system	
	Flexibility	Adaptability of sanitation system to new conditions and requirements	
Socio-Cultural	Acceptability	Perception towards sanitation system	
		Convenience attached to utilisation of sanitation system	

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