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Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

A participatory multi-criteria assessment
from a sustainability perspective
applied in Bahir Dar, Ethiopia

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Executive Summary

Solid Waste Management aims at protecting human health, preventing environmental degradation and recovering valuable resources; objectives that relate to proper waste collection services, adequate disposal facilities and contextual resource recovery schemes. In developing countries, municipal solid waste consists mainly of organic matter, which implies a high valorisation potential. Anaerobic digestion (AD) is a promising method for valorisation of biowaste as it combines efficient waste treatment with generation of valuable products in form of energy-rich biogas and nutrient-rich digestate. Yet many urban AD projects in developing countries face severe operational problems or have failed due to set-ups in terms of type of technology, scale, location or stakeholders' involvement that are unsuitable for the given context. One of the reasons for the discrepancy between high theoretical suitability of AD as biowaste treatment method and the observed low success rate of AD projects in developing countries can be found in the fact that AD installations are often chosen and applied based on theoretical potential alone. If assessment of feasibility takes place at all, only technical and short-term financial criteria are taken into account.

This thesis seeks to fill this gap by developing a tool for assessing feasibility of AD for urban biowaste in developing countries, using not only technologies but also broader sustainability as feasibility criteria (technological-operational, environmental, financial-economic, socio-cultural, institutional, policy & legal). The report explains AD first in general terms and presents an overview of the technological variety. Experiences and lessons learnt from AD project in developing countries and particularly in Ethiopia are incorporated in the assessment tool. Designed to be used in a participatory manner, the tool helps to identify strengths and weaknesses of a specific AD set-up. Four major factors are identified that influence the outcome of an urban AD project. In the developed tool, these factors are structured along four distinct yet interrelated dimensions, each answering a specific question:

1. **WHY?** What are the driving forces and motivations behind the initiation of the AD project?
2. **WHO?** Who are the stakeholders and what are their role, power, interest and means of intervention?
3. **WHAT?** What are the physical components and flows in the proposed AD chain?
4. **HOW?** How is the enabling environment (sustainability aspects) in the proposed AD system?

Each dimension includes an extensive set of questions. The purpose of the first three dimensions is to delineate the specific context of the AD project and to test if the project has been planned thoroughly. The fourth dimension comprises the six sustainability pillars (main criteria) mentioned above, each with several sub-criteria groups. A simple mathematical algorithm in the feasibility assessment matrix enables to combine the results of the assessment (scores) with the relative importance (weights) attributed by the stakeholders and taking into account the risk that things develop differently than planned or that the data used for the assessment is not reliable (uncertainty factors). To facilitate the assessment procedure and visualization of the feasibility results, an Excel version of the tool is developed. Following the questions through the tool is comparable with going through a checklist with relevant items to be considered in the planning and decision-making stage. Furthermore, disruptive constellations in the AD proposal under assessment are detected and made apparent; a prerequisite for addressing, clarifying and improving them with the corresponding stakeholders. In this respect, the assessment process itself contributes as much to the assessment as the generated results; they together create a sound basis for discussions that can lead to sustainable improvements.

Bahir Dar, a city of 220'000 inhabitants in the north-west of Ethiopia has a solid waste management in place that is characterized by a successful public-private-partnership resulting in recent improvements in terms of a 71% waste collection rate. Waste is still predominantly disposed on an open dumpsite. The current SWM in Bahir Dar is analysed and subsequently summarized in a stakeholder matrix and a process flow diagram. Mainly to enhance the financial sustainability of the current SWM by valorisation of the organic fraction of municipal solid waste (biowaste), the private waste collection company Dream Light initiated the Integrated Organic Recycling Centre which combines charcoal-briquetting, composting and anaerobic digestion technologies. The developed feasibility assessment tool was tested and discussed in a stakeholder workshop in Bahir Dar; an approach that was positively perceived as a signal of valuing different opinions and discussing them transparently. Comments by the stakeholders were used to improve the formulation of questions, adapt the assessment procedure and to simplify the tool. The thesis presents the results of the feasibility assessment as applied in Bahir Dar and highlights recommendations for further adaptations of the tool as well as of the AD project in Bahir Dar.

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... dedicated to Sämi (Taxi)

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Abbreviations

AD	Anaerobic Digestion
ANRS	Amhara National Regional State
ARARI	Amhara Regional Agricultural Research Institute
BD	Bahir Dar
BDU	Bahir Dar University
BoEPLAU	Bureau of Environmental Protection and Land Administration Use
BoH	Bureau of Health
CA	City Administration
CBA	Cost Benefit Analysis
CBO	Community Based Organization
CHP	Combined Heat and Power
C/N	Carbon to Nitrogen ratio
CSA	Central Statistical Agency
CSTR	Continuously Stirred Tank Reactor
DL	Dream Light PLC
EPA	Environmental Protection Authority
ETB	Ethiopian Birr
FfE	Forum for Environment
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HRT	Hydraulic Retention Time
ISWM	Integrated Sustainable Waste Management
MCDA	Multi-Criteria Decision Analysis
MSW	Municipal Solid Waste
NBPE	National Biogas Program Ethiopia
NGO	Non Governmental Organization
NIMBY	Not In My Back Yard
NPV	Net Present Value
OFMSW	Organic Fraction of Municipal Solid Waste (comparable to VFY or biowaste)
OLR	Organic Loading Rate
ORC	Organic Recycling Centre
PFD	Process Flow Diagram
PFR	Plug Flow Reactor
PLC	Private Limited Company
SBPD	Sanitation, Beautification and Park Development
SNV	Netherlands Development Organization
SRT	Solid Retention Time
SWM	Solid Waste Management
TNS	The Natural Step
TS	Total Solids
UNEP	United Nations Environmental Programme
VFA	Volatile Fatty Acids
VFY	Vegetable-Fruit-Yard waste (comparable to OFMSW or biowaste)
VS	Volatile Solids

Exchange rate (October 2011)

1 EUR = 23.44 ETB	(100 ETB = 4.27 EUR)
1 US$ = 17.35 ETB	(100 ETB = 5.76 US$)

1 Introduction

1.1 Background

Cities in developing countries are facing immense urban environmental management challenges as a result of rapid population growth, urbanization and industrial growth (Narayana, 2009). The challenges include, among others, provision of proper waste collection services, adequate disposal facilities and sustainable resource management. If unresolved, these issues can pose risks to public health and the environment: Uncollected waste often leads to clogging of drains, the subsequent stagnant water bodies support disease transmission by allowing insect breeding. Furthermore, the blocked drains can cause flooding during periods of intense rainfall. Heaps of indiscriminately dumped wastes attract domestic animals, rodents and other disease vectors and lead to leachate that contaminates surface and groundwater supplies. While uncontrolled burning of waste results in air pollution and can cause respiratory health problems, uncontrolled decomposition of organic wastes emits unpleasant odours and generates methane, a major greenhouse gas contributing to global warming. In addition, as results of the predominant practices of linear metabolism (cradle to grave), materials are often not recovered from waste, thus contributing to depletion of natural resources. Substantial amounts of essential nutrients (e.g. phosphorus) are lost in the agricultural food supply chain or end up on waste disposal sites (Scheinberg, Wilson & Rodić, 2010).

In order to minimize the risk to human health, avoid environmental degradation and recover valuable resources, proper solid waste management (SWM) is essential and seen as one of the key challenges of the 21st century (Scheinberg, Wilson & Rodić, 2010). Moving towards a sustainable waste management regime, increased emphasis is laid on diverting waste materials from disposal and directing them to valorization, thus recycling (circular metabolism: cradle to cradle) has become an essential and integrated part of municipal solid waste management (Van de Klundert & Anschütz, 2001). On the way from the traditional concept of 'end-of-pipe' *waste management* towards a more holistic and sustainable *resource management*, it is of crucial importance to find contextual solutions which are suitable for the social, economic and environmental local circumstances (Wilson, 2007).

Solid waste in most cities of low- and middle-income countries consists mainly of organic, hence biodegradable matter (Troschinetz & Mihelcic, 2008). Therefore, biowaste (elsewhere also named organic fraction of municipal solid waste) arguably deserves more attention than other materials in solid waste management. Moreover, biowaste comprises a great potential as a renewable resource to be used as substrate for different treatment methods generating valuable products. Through aerobic composting, a precious product with soil-enhancing properties can be produced that can contribute to reverse the process of loss of topsoil. Through anaerobic digestion (AD) biogas, a renewable energy source can be generated, while at the same time producing a nutrient-rich fertilizer. Direct animal feeding, insect larvae cultivation, charcoal-briquetting, and bio-refining are other options to valorise organic waste. To unlock the full potential of biowaste, it has to be adequately treated and valorized. Experiences have shown that waste management techniques as applied in industrialized countries are not directly applicable on developing countries due to social, economic and cultural differences (Gebren & Oelofse, 2009). Thus diverse technologies have been developed in search for appropriateness to various local contexts. However, the challenge remains of selecting the most appropriate technological set-up for a certain context so as to increase the chances for sustainable long-term operation of the system.

Ethiopia is one of the many developing countries in sub-Saharan Africa where municipal authorities are struggling to provide adequate urban environmental services. Bahir Dar in the north-west of Ethiopia is with 220'000 inhabitants the third largest and also one of the fastest growing cities in the country (UNEP, 2010a). If the current annual population growth rate of 6.6% continues, the city population will be doubled in just 11 years. Thus the need for adequate solid waste management (SWM) is unquestionable and acknowledged by the municipality (Mekete, Atikilt & Hana, 2009). In 2008, the municipality of Bahir Dar sub-contracted the waste collection service from households, commercials and institutions to the private company Dream Light (DL). As a consequence, the collection rate went up from 51% in 2005 (UNEP, 2010a) to 71% in 2010, leading to substantial improvement of the cleanliness in the city (UNEP, 2010b).
The United Nations Environmental Programme (UNEP) in collaboration with the Ethiopian NGO Forum for Environment and local stakeholders has launched several activities as part of an Integrated Sustainable

Waste Management (ISWM) plan for Bahir Dar. As a complementary service, Eawag/Sandec, Switzerland, supports the improvement of the current SWM in Bahir Dar by conducting different research studies.

1.2 Problem statement

The collected unsegregated waste in Bahir Dar ends up at an open dumpsite without any treatment. Thus public health and environmental problems are simply shifted to the peripheral area of the city where the dumpsite is located. In addition, the collection services are not financially sustainable partially due to the low payment rate by the service users. Moreover, income is lost because the potentially valuable organic waste is currently being dumped without making use of its potential by valorisation (UNEP, 2010b). In recognition of this problem, recommendations have been given in the document 'Target Settings for ISWM in Bahir Dar City' to develop biogas plants for the treatment of the organic solid waste (UNEP, 2010c). As a result, an AD system for municipal organic waste has been planned, designed and construction started in 2011 as part of Dream Light's Organic Recycling Centre (ORC) in Bahir Dar.

A considerable number of urban AD projects in developing countries have failed, which is to a certain extent due to limited experiences with AD of biowaste in low- and middle-income countries in general (Mshandete & Parawira, 2009). Before implementation of an urban AD-project, an in-depth study would be very useful to assess the feasibility of the proposed anaerobic digestion technology. A feasibility study can help to minimize the risk of installing an AD-treatment chain that is unsuitable in scale, technology, location and stakeholders responsibilities. According to Rapport et al (2008), *"the design of any new digester facility should be based on a thorough feasibility study and special attention should be paid to all aspects of the treatment process, including waste collection and transportation, pre-treatment, material handling, post-treatment, public education and strategic siting of the system."* It is a widespread problem that technologies like AD are chosen and applied based on theoretical potential alone, without any feasibility assessment at all. If assessment of feasibility takes place, then solely technical and short-term (investment stage) financial criteria are used. This was also the case in Bahir Dar where a techno-economic study has been conducted by the company responsible for designing and constructing the technologies of the Organic Recycling Centre. However, in order to find the most suitable AD set-up for the contextual circumstances, an approach is needed that uses sustainability as feasibility criteria and involves the stakeholders. On municipal level like in Bahir Dar, this requires thorough knowledge of stakeholders, processes and flows in the current municipal solid waste (MSW) system, as well as a general understanding of the technological variety for anaerobic digestion of biowaste. Furthermore, a feasibility assessment tool for participatory evaluation of the proposed anaerobic digestion approach and technology is needed.

1.3 Objectives and research questions

The overall objective is to develop a feasibility assessment framework for anaerobic digestion technologies treating municipal biowaste in developing countries by taking into consideration technological-operational, socio-cultural, financial-economic, environmental, institutional and policy & legal aspects related to the design, construction and operation of such AD technology.

To facilitate feasibility assessments of urban AD projects, this thesis aims at developing a tool that…

- is well structured and contains a clear logic
- uses sustainability as feasibility criteria
- uncovers requirements for successful AD projects
- reveals differences in stakeholder perspectives and priorities
- creates basis for discussion
- quantifies feasibility
- enables testing the capacity of the institution responsible for design & installation of the system
- is general enough to allow assessing the whole variety of AD technologies for biowaste and specific enough to deliver precise results corresponding to the local context
- can be used for comparison of AD technologies
- helps to increase sustainability of projects proposed

This feasibility assessment tool is applied in Bahir Dar, Ethiopia.
The specific objectives and related research questions raised in order to accomplish the overall objective are as follows:

I) **To get insight into the current situation of MSW management** in Bahir Dar
   a. Who are (formal and informal) actors; which interactions, processes and waste flows constitute the current management of MSW in Bahir Dar?

II) **To provide a brief overview of AD for biowaste including existing AD technologies** and give insight into anaerobic digestion development in Ethiopia
   a. Which technologies have been implemented for anaerobic treatment of biowaste in low- (focus on Africa), middle-, and high-income countries?
   b. What are some of the activities that have been undertaken in the field of anaerobic treatment of biowaste (including sanitary waste treatment) in Ethiopia?

III) **To develop a methodology for assessing the feasibility of anaerobic digestion technologies** treating biowaste in developing countries
   a. Which technological criteria need to be included and how can they be complemented by criteria developed under the sustainability domains (social, economic, environmental, institutional and legal)?
   b. What are strengths and weaknesses from AD projects in low- and middle-income countries and how can the 'lessons learnt' be integrated in the feasibility assessment tool?
   c. How can these criteria be quantitatively used, meaningfully interpreted and appropriately visualized in order to identify strengths & weaknesses of the proposed technological set-up?

IV) **To apply the developed feasibility assessment tool on the proposed AD project in Bahir Dar** and critically analyze the results
   a. How do the assessments of the different main stakeholders differ from each other?
   b. Based on the results of the feasibility study elaborated under objective III), how feasible is the proposed AD concept in Bahir Dar in terms of technological-operational, socio-cultural, financial-economic, environmental, institutional and policy & legal criteria and which aspects need specific attention to increase the chances of sustainable operation?
   c. What are the recommended further steps/adaptations for the tool and proposed AD system?

1.4 Scope, limitations and outline of thesis

The focus of this thesis is on anaerobic digestion (AD) and more specifically on developing a tool that allows assessing the feasibility of AD for municipal biowaste. It is explicitly developed to address the urban context of developing countries. Other treatment options for organic waste like composting and briquetting are only taken into consideration to the extent required in the given situation in Bahir Dar. The list of potential AD technology options contains exclusively already existing and successfully implemented technologies i.e. technology innovations and developments of new technologies are not included.

Chapter 2 presents the conceptual framework of this thesis research by explaining the approach and the main concepts used, while **chapter 3** describes the methodology applied. **Chapter 4** gives an introduction into Bahir Dar by stating general facts and figures and presenting a detailed portrait of its current solid waste management (SWM) situation – thus giving the answer to research question I. **Chapter 5** provides an overview of anaerobic digestion (AD) for biowaste by describing its history, the AD process chain and the different AD technology in use. A visual classification model is applied for quick grasp of the most relevant characteristics of different technologies. The chapter ends with providing insight into the current situation and development of AD in Ethiopia. This chapter thus answers research question II. **Chapter 6** presents the idea and structure behind the feasibility assessment tool for urban AD developed in this research study and explains the main categories of the assessment matrix, thus answering research question III. **Chapter 7** describes the application of the feasibility assessment tool in Bahir Dar and reveals its results and the feedbacks of the participants (research question IV). **Chapter 8** critically reflects on the strengths and weaknesses of the used methods, the tool and the proposed AD project in Bahir Dar, before presenting some overall conclusions and final recommendations in **chapter 9**.

2 Conceptual framework

2.1 Reflexive engineering approach

This thesis is conducted in a “reflexive engineering” manner, a term that was developed by Robbins (2007), who distinguishes two types of engineers: the traditional engineers and reflexive engineers. The traditional engineers have their professional identity “rooted in feelings of self-importance and a belief to lead, based on qualities of technical expertise”, while possessing the abilities to solve social problems using science and logic. Thus the traditional engineers’ world view is rather elitist and hierarchical.

The second group of engineers labelled ‘reflexive engineers’ have a much more integrated ethical and system-based approach to development. This approach values communities and the environment in which they are sited as well as the technology. Core components of reflexive engineering involve:

- Having a holistic and flexible understanding of socio-technical dynamics
- Seeing publics as resource and partners in decision-making processes
- Viewing education as a two-way process between engineers and communities
- Striving for a multifaceted understanding of social, economic and environmental barriers to uptake for new technologies
- Having an integrated approach to technological problems and solutions

Robbins (2007) argues that many of the challenges faced in the South are as much social as they are technological and therefore reflexivity is an important and promising way in which engineers can engage with real problems in developing countries.

2.2 Sustainability concepts

The term ‘sustainable development’ was coined in 1987 by the Brundtland Commission and offered the world a new perspective on how to address the challenge of advancing economic development while protecting Earth’s ecological systems and enriching the quality of life for this and future generations (WCED, 1987). The universality of sustainable development as a unifying and holistic paradigm appeals to many and as a result the concept has been widely accepted (Sahely, Kennedy & Adams, 2005). Sustainability is not one item of a list of relevant considerations in decision making, but a broad conceptual framework and set of general values for integrating the full suite of relevant considerations. It covers all core issues of decision making: The pursuit and maintenance of necessities and satisfactions, health and security, diversity and equity, ecology and community, preservation and development (Gibson, 2005). To date, most sustainability efforts have been based on the well-known social-economic-ecological three-legged stool that has directed many projects towards considering the different factors of a system (Buchholz, Volk & Luzadis, 2007). This popular three-pillar version is convenient, because it corresponds with traditional fields of policy making, scholarly enquiry and specialized research (Gibson, 2005). This thesis uses the (slightly adapted) sustainability aspects as defined by van de Klundert & Anschütz (2001): Technological-operational, environmental, financial-economic, socio-cultural, institutional, policy&legal. Other authors use different categories for sustainability, e.g. Hellström, Jeppsson & Kärrman (2000) who name the five main sustainability categories as: Health and hygiene, socio-cultural, environmental, economic, functional-technical. It has been estimated that some three hundred definitions of 'sustainability' and 'sustainable development' exist broadly within the domain of environmental management and the associated disciplines (Johnston et al, 2007). However, any definition of sustainability in literature contains the following overarching key themes (Sahely, Kennedy & Adams, 2005):

- Proper assessment of relevant environmental, economic and social factors
- Consideration of expanded temporal horizons (short-term and long-term well being)
- Consideration of expanded spatial horizons (local and global level)
- Intergenerational equity, i.e. a need for systems to be adaptive to given changing circumstances
- The need for multi-disciplinary considerations

Gibson (2005) describes these key themes as a challenge to conventional thinking and practice, points out their links and interdependencies and emphasizes the open-ended process rather than a static one. He adds that the concept of sustainability is best perceived as a substantially important but minimal framework requiring specification in and for particular places.
The main methodological obstacle for putting sustainable development in practice is the translation of principles into operational models. On the search for operationalisation of sustainability, several challenges are encountered: Joyce (2003) describes this as follows: *"The challenge is to do planning and decision making while balancing three tensions: 1) maintaining scientific credibility 2) assuring practical saliency, and 3) legitimizing the process to multiple participants."*

On his quest of how to define sustainability in terms of robust operational principles, the Swedish scientist Karl-Henrik Robèrt embarked upon a systematic consensual and heuristic approach. He arrived at four 'system conditions' (principles of sustainability) that are based on the scientific foundation of the Laws of Thermodynamics and studies of humans as a social species. The principles were defined and refined through consultation with members of the scientific community, reaching an eventual consensus position in 1992 (Johnston et al., 2007). The system conditions have subsequently been put to use in a framework that includes logical guiding principles. This science based approach to 'sustainability' and 'sustainable development' has become known as 'The Natural Step Framework' (TNS) after the organization promoting it. TNS Framework bases its planning approach on a concept called 'backcasting from principles': The four TNS system conditions define a stage, a favourable outcome, a vision in the ecosphere/society from where it can be planned what needs to be done to move towards that point. These conditions are limits that cannot be violated if we want to develop a sustainable society, product or technology. The four system conditions are stated as (Robert, 2000):

"In the sustainable society, nature is not subject to systematically increasing…
1. … concentrations of substances extracted from the Earth's crust.
2. … concentrations of substances produced by society.
3. … degradation by physical means and
4. People are not subject to conditions that systematically undermine their capacity to meet their needs."

The system conditions relate to the whole biosphere with its human societies and thus needed to be rephrased in order to make it relevant at the level of the individual. This was done by using the principle of 'eliminating our contribution' (Johnston et al., 2007).

Hence, operational sustainability principles would aim to eliminate our contribution to…
1. … systematic increase in concentrations of substances from the Earth's crust.
2. … systematic increase in concentrations of substances produced by society.
3. … systematic physical degradation of nature.
4. … conditions that systematically undermine people's capacity to meet their needs.

As an illustration, this means that in a sustainable society, the technologies and products do not require...
1. ... mining and dispersing materials extracted from the Earth's crust (e.g. oil, coal, metals) faster than they can be returned to the Earth's crust.
2. … producing substances (e.g. toxic compounds like DDT, PCB's, dioxins) faster than they can be broken down by natural processes.
3. ... depleting or degrading resources faster than they are regenerated (e.g. over-harvesting of trees), or by other forms of ecosystem manipulation (e.g. paving over fertile land or causing soil erosion).
4. ... conditions that undermine people's capacity to meet their basic human needs (e.g. unsafe working conditions, insufficient salary to live from).

The first three system conditions provide a neat, straightforward and yet comprehensive set of criteria to assess environmental sustainability while the fourth one helps to test social sustainability. Such as test (check) is periodically needed to ensure that the development is in fact sustainable. Elghali et al. (2007) state that three sets of criteria are usually recognised as representing the test for sustainability (according to the three sustainability pillars): Economic viability in the market and financial framework within which the supply chain operates, environmental performance and social acceptability, with the benefits recognised as outweighing any negative social impacts.

The sustainability paradigm implies a need for ensuring that appropriate stakeholders are involved in the decision-making process (Loucks & Gladwell, 1999). Particularly, there is a strong need for participation of *local* stakeholders in order to tap their perceptions and knowledge when pursuing sustainability (Buchholz, Volk & Luzadis, 2007). Furthermore, operationalisation of uncertainty and risk i.e. putting value on them is inherently subjective and therefore justifies a participative process involving concerned stakeholders. It is widely acknowledged that broad stakeholder participation reduces uncertainty (Buchholz, Volk & Luzadis, 2007).

2.3 Integrated Sustainable Waste Management

Integrated Sustainable Waste Management (ISWM) is a framework that was first developed during the mid 1980s by the Dutch NGO WASTE and its South partner organizations. It was further developed by the Collaborative Working Group on Solid Waste Management in Low- and Middle-Income Countries (CWG) in the mid 1990s. Since then it has become the 'norm' (Anschütz, Ijgosse & Scheinberg, 2004).

ISWM provides an analytical framework for first understanding the problems and secondly looking for appropriate solutions (Van de Klundert & Anschütz, 2001). It has the goal to optimize between minimizing negative impacts on health and environment and maximizing economic benefits (Zurbruegg et al, 2011). ISWM is a systems approach to waste management that recognizes three important dimensions of waste management which all need to be addressed when developing or changing a solid waste management system. Each of the three dimensions answers a question:

1) **Stakeholders (WHO?)**
   Stakeholders can be defined as actors who have a stake, an interest in the issue under consideration, who are affected by it, or who- because of their position- have or could have an active or passive influence on the decision-making and implementation processes (Varvasovszky & Brugha, 2000). Stakeholders have various interests and roles. The main stakeholders in SWM include local authorities, NGOs/CBOs, service users, private informal sector, private formal sector and donor agencies. Their *power* (the extent to which they are able to persuade or coerce others into making certain a decision or following certain courses of action) varies as well as their *interest* (the extent to which a certain issue is given priority).

2) **Physical system components (WHAT?)**
   These are the technical components of a waste management system from waste generation and separation to collection, transfer and transport, resource recovery and disposal. Part of the purpose of using the ISWM framework is to show that these technical components are part of the overall picture and not all of it.

3) **Sustainability aspects or enabling environment (HOW?)**
   For a waste management system to be sustainable, all of the operational, financial, environmental, social, institutional, political and legal aspects need to be considered. These aspects provide a series of analytical 'lenses' which can be used for assessing the situation, determining feasibility, identifying priorities or setting adequate criteria.

UN Habitat (Scheinberg, Wilson & Rodić, 2010) further includes three **development drivers (WHY?)** for the development of each of the three main physical components:

a. Public health as driver for effective waste collection
b. Environment as driver for sound (treatment and) disposal of the waste
c. Resource management as driver for high rates of organics recovery, reuse and recycling (valorization of recyclables and organic materials)

Figure 1 presents a modified scheme of the ISWM framework with its dimensions and the questions they answer (including the WHY-dimension from UN-Habitat methodology).

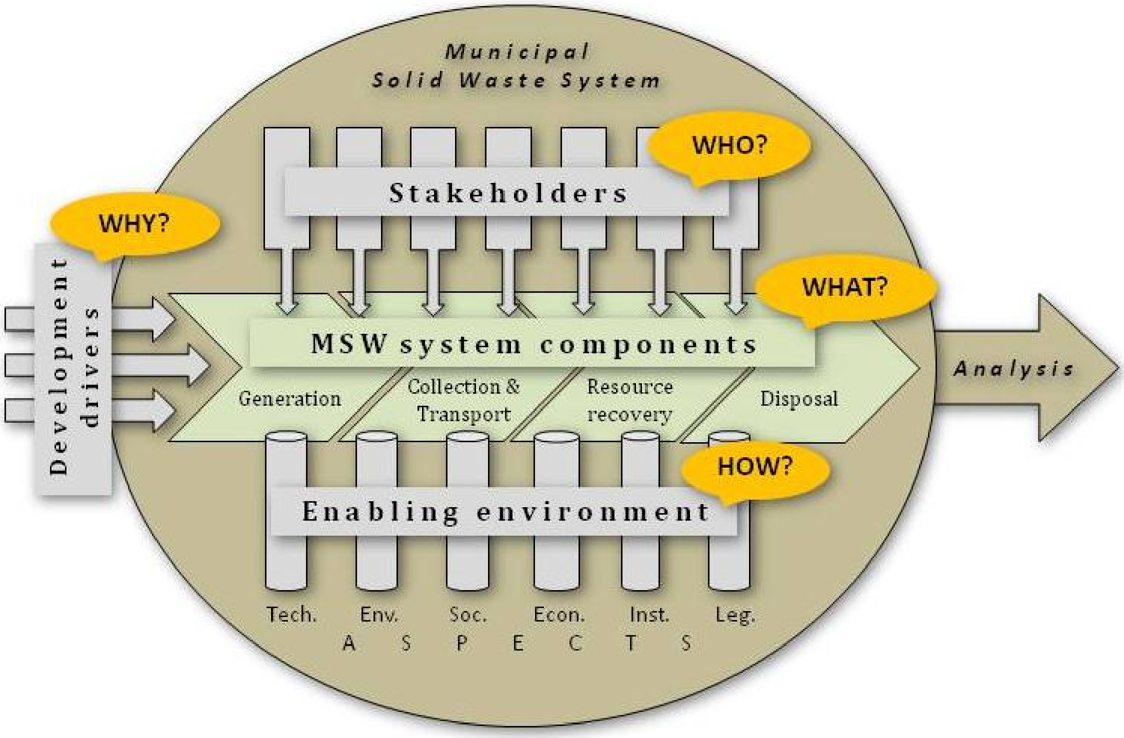


Figure 1: The integrated sustainable waste management framework, adapted from WASTE, 2001

2.4 Feasibility assessments in decision-making processes

Environmental planning and decision-making are often complex, multi-faceted, essentially conflict analyses characterized by socio-political, environmental and economic value judgements involving typically a large number of decision-makers with different priorities or objectives (Lahdelma, Salminen & Hokkanen, 2000; Linkov et al., 2004). Thus for successful implementation and long-term operation of environmental technologies particularly in developing countries it is of crucial relevance to base the decision regarding type of technology, scale and location on an informed, participatory and transparent assessment process. This decision needs to take into account the skills and capacities, organizational structures, institutional and legal framework, social acceptance, ecological context and economic base of the given situation.

The primary objective in assessment processes is to develop ways to provide accessible and practically useful information on selected supply chains and scenarios to support short-term planning decisions and long-term developments (Elghali et al., 2007). The assessment consists of several distinct steps:

- Determine the contribution of the technology and related supply chain towards sustainable development objectives at different scales over time (local, regional, national)
- Identify any trade-offs between competing objectives
- Provide insight into the practical drivers and constraints for different actors along the supply chain
- Identify any gaps in knowledge and issues which will need to be addressed in future studies.

The approach needs to be designed to develop sets of attributes that will represent the sustainability of technological systems and capture the concerns of all relevant stakeholders. Of interest is not whether the process leads to a decision that satisfies the wishes of any sector group or stakeholders, as different groups have different concerns and objectives; the interest lies in whether the process is able to integrate and reconcile different objectives (Elghali et al., 2007).

Multi Criteria Decision Analysis (MCDA)

MCDA has been developed as a decision-making tool for complex multi-criteria problems that include quantitative and/or qualitative aspects of the problem (CIFOR 1999). It aims at simplifying complex systems by using a restricted number of criteria and structuring them in a way that clarifies relationships, impacts and outcomes while incorporating many stakeholders (Buchholz, Volk & Luzadis, 2007). The objective of MCDA methods is to improve the quality of decision processes so that demands for transparency, coherence, consistency and comprehensiveness can be met (Salo & Hämäläinen, 2010). By applying MCDA, intuitive choices are replaced by a justified and jointly accepted model (Lahdelma, Salminen & Hokkanen, 2000). One of the advantages of an MCDA approach in group decisions is the capacity for calling attention to similarities or potential areas of conflict between stakeholders with different views, which results in a more complete understanding of the values held by others (Linkov et al., 2004), hence the multicriteria planning process enables bidirectional learning between experts and interest groups (Lahdelma, Salminen & Hokkanen, 2000). There are many MCDA techniques and their number is still rising (DCLG, 2009). For this thesis work, only certain elements of MCDA have been integrated in the tool (further described in chapter 6).

2.5 Research procedure

Figure 2 presents the scheme of the procedural approach to this thesis. A preparatory literature survey (6 June – 11 August 2011) is followed by a 3-month field study (12 August – 11 November 2011) in Bahir Dar. The literature study, depicted as the outer square in Figure 2, focuses on four main topics: anaerobic digestion and three topics that form the conceptual framework of this thesis.
Combining the information from literature with the data collected during the field research enables answering the related research questions (RQ).

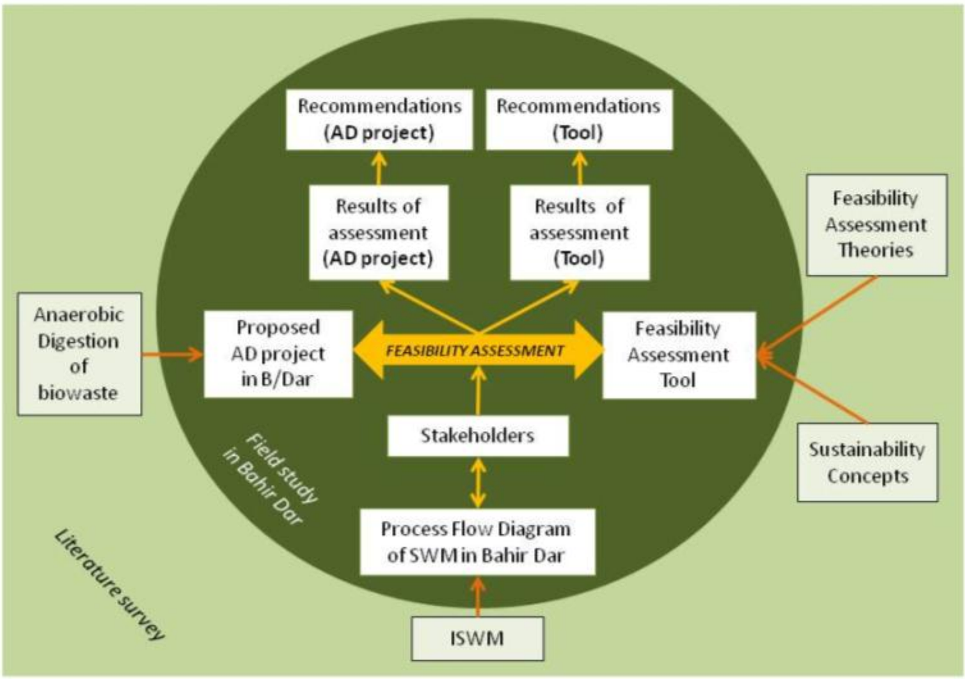


Figure 2: Research procedure of this thesis

The four main topics have been chosen as preparation and fundament for the field work in Ethiopia due to the following reasons: Integrated Sustainable Waste Management (ISWM) is a widely accepted and applied concept worldwide. It includes qualitative and quantitative inquiry tools that help to understand the current SWM system and to find contextual solutions for improvements. Sustainability as an overarching concept is relevant for sound human development in general and for this study in particular because the feasibility assessment uses sustainability as criteria for feasibility. Feasibility assessment literature was examined to understand the existing methods of conducting feasibility studies. Anaerobic Digestion (AD) of biowaste forms the technological basis of this study, thus profound knowledge about the AD process and the implemented technologies is an essential prerequisite for any AD assessment.

3 Methodology

The following section describes the methods used for answering the individual research questions. The two main approaches used are literature study (2 months), fieldwork research in Bahir Dar (3 months, see Appendix I for schedule of fieldwork) and finalization of the report after the return (1.5 month).

- **RESEARCH QUESTION I**
  - Research question I) a: Who are (formal and informal) actors; which interactions, processes and waste flows constitute the current management of MSW in Bahir Dar?

    - Secondary data is collected by consulting literature describing the current solid waste system in Bahir Dar. The SWM assessment conducted by UNEP (2010a/b/c) is particularly central and its information about managing municipal solid waste is cross-checked by primary data gathered through observations and interviews. For this purpose, a general questionnaire based on the ISWM concept answering the four questions WHY?, WHO?, WHAT? and HOW? is developed (see Appendix IV for the complete questionnaire) and for each interview the relevant specific questions are prepared in advance. The interviews are recorded and afterwards transcribed, grouping answers belonging to the same questions underneath each other in order to make differences in stated facts and opinions apparent.
    - The interviewed stakeholders are asked to rate the *power* and *interest* of each stakeholders in the current SWM system on a scale from 1 to 10. The averages of all scores are illustrated in a stakeholder matrix.
    - The two Sandec/Eawag students who conducted their research studies on SWM in Bahir Dar (Camenzind and Worku) prior to this research are consulted for issues related to financial aspects and recycling practices respectively.
    - After having compiled all answers required for understanding the different dimensions of the SWM in Bahir Dar, a Process Flow Diagram (PFD) is drawn. A PFD presents the total picture of a solid waste system at a glance, as it illustrates the process steps and the movement of waste material streams between them. This implies several distinct advantages: All waste streams are accounted for, losses are exposed, system boundaries are clearly denoted, no activities forgotten, final destinations of waste materials are stated, and the place and contributions of all stakeholders are visible (Rodić, Scheinberg & Wilson, 2010).

- **RESEARCH QUESTION II**
  - Research question II) a: Which technologies have been implemented for the anaerobic treatment of biowaste in low- (focus on Africa), middle-, and high-income countries?

    - Literature review is conducted to assemble the existing information about AD of biowaste.
    - Dr. G. Zeeman (WUR) is consulted to integrate her experience and expertise in the field of AD.

  - Research question II) b: What are some of the activities that have been undertaken in the field of anaerobic treatment of biowaste (including sanitary waste treatment) in Ethiopia?

    - Internet search is combined with literature research
    - Visits to institutional AD project in Bahir Dar (and a few selected AD projects in Addis Ababa) are undertaken in order to examine their level of operation and to understand the problems related to different systems.
    - Actors with knowledge and experience in the AD field of Ethiopia (particular focus on Bahir Dar, but also Addis Ababa) are contacted and where possible personally met. During the resulting interviews, the people are questioned about their experiences with AD in Ethiopia (special focus on urban AD projects) and the encountered problems.

- **RESEARCH QUESTION III**
  This entire research question is answered by means of Multi-Criteria Decision Analysis.

- Research question III) a: Which technological criteria need to be included for assessing the feasibility of anaerobic digestion technologies and how can they be complemented by criteria developed under the sustainability domains (social, economic, environmental, institutional and legal)?

  - Based on literature research, a set of criteria is developed and local AD experts consulted for their opinion. The feasibility assessment catalogue is brought along when visiting AD projects in Ethiopia and adapted according to the gaps, inconsistencies or ambiguities detected.
  - Cost-Benefit Analysis (CBA) is used as a help for rational decision making. It includes a systematic cataloguing of impacts as benefits (pros) and costs (cons), translating them in monetary values and then determining the net benefits of the proposal relative to the status quo (Boardman et al., 2006).

- Research question III) b: What are strengths and weaknesses from AD projects in low- and middle-income countries and how can the 'lessons learnt' be integrated in the feasibility assessment tool?

  - Combining a literature study on existing AD projects in developing countries and personal experiences and observations, a catalogue of important points to be included in the feasibility assessment tool is elaborated.
  - In addition, AD experts in Ethiopia are asked about their experiences with AD projects (strengths and weaknesses); their comments are integrated in the feasibility assessment tool.

- Research question III) c: How can these criteria be quantitatively used, meaningfully interpreted and appropriately visualized in order to identify strengths and weaknesses of the proposed technological set-up?

  - Based on literature about Multi-Criteria Decision Analysis a mathematical algorithm for scoring, weighting and allocating uncertainty factors is developed and tested. Its results are illustrated in a model that enables understanding of the concerns and benefits of the stakeholders involved in the proposed AD project.

- **RESEARCH QUESTION IV**
- Research question IV) a: How do the assessments of the different stakeholders differ from each other?

  - Selected stakeholders from the proposed AD system are invited to participate in testing the feasibility assessment tool. This testing takes place in form of a multi-stakeholder workshop in Bahir Dar. The results of the assessments are discussed within the stakeholder group.

- Research question IV) b: Based on the results of the feasibility study elaborated under objective III), how feasible is the proposed AD concept in Bahir Dar in terms of technological-operational, socio-cultural, financial-economic, environmental, institutional and policy & legal criteria and which aspects need specific attention to increase the chances of sustainable operation?

  - The feasibility assessments as conducted by the stakeholders are analyzed by making the strengths and weaknesses apparent and giving concluding comments related to each set of criteria.

- Research question IV) c: What are the recommended further steps/adaptations for the tool and the proposed AD system?

  - Based on the procedure and results of the feasibility assessment, issues of concerns are discussed with stakeholders to come up with recommendations regarding improvement of the tool and enhanced sustainability of the proposed AD system.

4 Solid Waste Management in Bahir Dar

4.1 Facts and figures about Bahir Dar

- **General**

Bahir Dar is the capital city of Amhara National Regional State (one of the 9 regional states of the federal democratic republic of Ethiopia) and with roughly 220'000 inhabitants constitutes Ethiopia's third-largest city. It is located in the north western region of Ethiopia (560 km from Addis Ababa), at the south side of Lake Tana on an altitude of 1800 meters above sea level. Its location at Lake Tana explains Bahir Dar's name (Amharic for 'sea shore'). The city and its surroundings are a major tourist hub because of the rich cultural, historical and natural heritages.

Figure 3: Map of Ethiopia with flag and location within Africa in top right corner [1, 2, 3]

Bahir Dar was awarded *UNESCO Cities for Peace Prize* in 2002 for managing to address the challenges of rapid urbanization. In its address, the General-Director of UNESCO mentioned that *"the city has shown great determination in its efforts to tackle difficult issues such as housing shortages, economic stagnation, and lack of electricity by using local labor to find solutions and providing adequate public services. These actions have improved living conditions for the most vulnerable groups of society and have encouraged the community to work together to build a common future."* (UNESCO, 2002).

The most important geographic information about Bahir Dar is listed in Table 1.

Table 1: Geographic information about Bahir Dar

City	Bahir Dar	Source
Country	Federal Democratic Republic of Ethiopia	
Region/State	Amhara National Regional State	
Continent	Africa	
Coordinates	11°38' N, 37°10' E	(UNEP 2010a)
Altitude	1790 – 1840 meters above sea level	[4]
Topography	Mainly flat and plain, surrounded by hilly features	
Size of City/Urban Area	278 km2 (urban & rural kebeles), 160 km2 (urban kebeles: core city)	(UNEP 2010a)
Administrative districts	9 urban kebeles and 4 rural kebeles	(UNEP 2010a)

- **Climatic information**

The tropical climate in Bahir Dar is characterized by a rainy season (May - October) and a dry season (November - April). The average annual rainfall amounts to 1499 mm [4]. The average annual temperature is between 17-19°C.

Figure 4 presents the monthly mean temperatures and rainfall quantities as recorded from 1961-2000 [4].

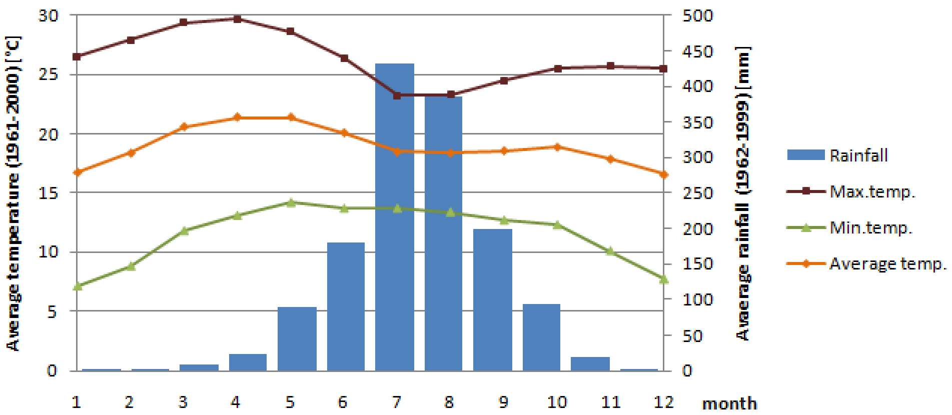


Figure 4: Monthly mean temperatures and rain-fall quantities in Bahir Dar from 1961-2000 [4]

- **Administrative organization and Land Use**

The city is divided in 9 administrative units called kebeles and each kebele is further divided into zones (see Appendix II for map of Bahir Dar and its kebeles). This study solely focuses on the 9 urban kebeles and does not take into consideration the 4 rural kebeles. Most of the kebeles comprise mixed land use i.e. residential, commercial, institutional etc. (Table 2).

Table 2: Kebeles in Bahir Dar (UNEP, 2010a)

Kebele type	Kebele name	Population	Hotels, restaurants, juice centers	Garages, shops, markets centers	Schools, colleges, universities	Gov't. / non-gov't bureaus, bank	Hospitals, clinic, health care centers
Urban keb. 1	Fasilo	19'905	16	73	13	43	3
Urban keb. 2	Sefene Selam	21'250	481	3'890	6	24	7
Urban keb. 3	Shumabo	24'484	33	173	6	21	1
Urban keb. 4	Hidar 11	30'000	31	0	18	17	5
Urban keb. 5	Gishabay	17'874	164	818	3	3	7
Urban keb. 6	Shimbit	14'754	39	429	7	39	6
Urban keb. 7	Ginbot 20	16'796	15	125	7	18	1
Urban keb. 8	Tana	13'703	25	290	6	21	2
Urban keb. 9	Belay Zeleke	20'000	31	407	6	5	1
Total		180'768	835	6205	72	191	33

Table 3 reveals the different land use and their share of the total city area.

Table 3: Land use of Bahir Dar (UNEP, 2010a)

Land Use	Area [ha]	Percentage of total land [%]
Water body	8'718	31.39
Agriculture	6'588	23.72
Formal urban settlement	4'214	15.17
Rural settlement	2'982	10.74
Vacant & Rocky	2'327	8.38
Marshy land	1'880	6.77
Informal settlement	992	3.57
Forest & Woodland	70	0.25
Total	27'771	100.00

According to a recently finalized cadastral surveying work of Bahir Dar City, about 30% (9'000) of the city houses are identified as informal settlements i.e. constructed on state owned or farmers' land without permission (Weldegebriel, 2011). These 30% of houses are built on only 3.57% surface area, whereas the remaining 70% take up 15.17% of land, indicating how densely populated informal settlements are.
Information about domestic infrastructures in Bahir Dar (drinking water, toilet facilities, cooking fuel and lighting) can be found in Appendix III.

- **Social parameters**

After the regional government has chosen Bahir Dar to be the capital of the Amhara National Regional State in 1999, the city as well as its population has been growing alarmingly fast. Of the roughly 220'000 persons inhabiting Bahir Dar, 82% live in the 9 urban kebeles and 18% in rural areas. With an annual population growth of 6.6%, the city is one of the fastest growing cities in the country (UNEP, 2010a) leading to a predictive doubling of the city population in just 11 years.
Ethiopia's Human Development Index (HDI) is 0.328, which gives the country a rank of 157 out of 169 [5]. Table 4 presents further information related to the inhabitants of Bahir Dar.

Table 4: Social parameters of Bahir Dar

Parameter		Source
Population	220'344 (Male: 107'578 female: 112'766)	[5]
Urban	180'094	[5]
Rural	40'250	[5]
Population density	5'973/km2	[6] (CSA2005)
Population Growth Rate 2007	6.6%	(UNEP 2010a)
Average Household Size	4.4	(2005) (UNEP 2010a)
Housing Units	61'250	(CSA, 2007; Amhara1) [7]
Households	62'960	(CSA, 2007; Amhara1) [7]
Human Development Index	0.328	[8]
Life expectancy	56.1 years	[8]

Of the approximately 80 ethnic groups present in Bahir Dar, the vast majority of people belong to the ethic group of the Amhara (96.2%), followed by the Oromo (1.1%) and Tigrie (1.1%) (CSA, 2007; Amhara1). The religious affiliation of people living in Bahir Dar is as follows: 89.7% are Orthodox Christian, 8.5% Muslims and 1.6 % are Protestants (CSA, 2007; Amhara1).

- **Economic Indicators**

The major economic activities practiced in Bahir Dar include trade, tourism and recreation, informal sector involvement and urban agriculture (Kassa, 2009). Due to the rapid expansion of the tourism sector, the hotel industry has become a very fast growing industry in the area (EIA, 2011).
Nine major industries are situated in Bahir Dar: 1 textile, 1 tannery (processing of raw leathers), 2 leathers (leather product-making), 2 agro-industries, 1 oil, 1 plastic, 1 abattoir (UNEP, 2010a). The GDP (composition per sector) is as follows: Agriculture (42.9%), industry (13.7%), services (43.4%) [estimate for 2010; 9].

Table 5: Economic indicators for Ethiopia

	Country	Per Capita
Gross Domestic Product (GDP, current prices)	29.12 billion US$ (2010 est.) [9]	324 US$ [11]
Legal minimum wage per month	None [10]	None
Per Capita Income (annual)	-	1000 US$ (2010 est.)
Individuals/families below Poverty Level	38.7% (2005/06) [9]	-

The national currency is Ethiopian Birr (ETB). In October 2011, 1 EUR was 23.44 ETB (1 US$ = 17.35 ETB).
The different income-groups are currently classified into: low-income: < 400 ETB/pers./month, middle-income: 400 – 2'000 ETB/pers./month, and high-income: >2'000 ETB/pers./month (Alemnew, 2011; Getahun, 2011).

Table 6: Growth indicators for Ethiopia [sources are indicated in brackets]

Year	GDP (current prices; US$)	GDP per capita (current prices; US$)	Population Ethiopia	Population Bahir Dar	Population Growth Rate (%) Bahir Dar
1984	8'315 Mio [12]	209.23 [12]	39.74 Mio [12]	54'766 [4]	n.a.
1994	8'077 Mio [12]	146.24 [12]	55.23 Mio [12]	94'245 [4]	5.4 [4]
2005	12'307 Mio [12]	164.83 [12]	74.66 Mio [12]	168'048 [4]	5.3 [4]
2007	19'553 Mio [12]	248.62 [12]	78.65 Mio [12]	220'344 [5]	6.6 (UNEP, 2010a)
2009	32'249 Mio [12]	389.43 [12]	82.81 Mio [12]	n.a.	n.a.

4.2 Current solid waste management in Bahir Dar

The following section is structured in four sub-chapters according to the three dimensions of the SWM concept plus one additional introductory dimension related to drivers and state of modernization of the current SWM system (Figure 5, for more detail see 2.2). The general questionnaire used as guidelines for the interviews can be found in Appendix IV

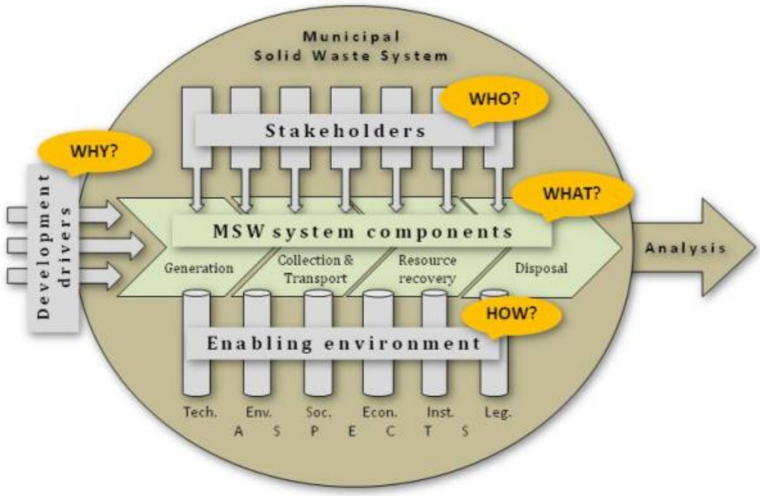


Figure 5: The integrated sustainable waste management framework, adapted from WASTE, 2001

4.2.1 Development drivers (WHY?)

In this section, the development of solid waste management in Bahir Dar is briefly explained, including the driving forces that have brought about this development.

Until 2008, Bahir Dar had a SWM system named 'bring-system' or 'communal container system' where waste was brought to a communal container on the street. The principal stakeholders in that system included the waste generators (households, commercials, institutions), the Sanitation and Beautification Team of the municipality and the informal waste collectors (Kassa, 2009).

- The waste generators had the responsibility to store the solid waste at home and have it transported by themselves, their children, house servants or by informal waste collectors from the source of generation to one of the 70 metal containers (à $8m^3$).
- The informal waste collectors went from door-to-door and collected waste either on client basis or by asking if people have solid waste to be disposed of. The reward for the collection services was either in kind (mostly food) or in cash. The payment ranged from 0.5 ETB to 2 ETB per each collection event, depending on the quantity of the waste and the distance to the container site (Kassa, 2009).
- The municipality offered its services through provision of 70 temporary waste storage containers distributed throughout the city. Each of these metal containers had a capacity of $8m^3$ and was guarded by a municipality guard. To that end 70 container guards were employed with the duty to send people away when containers were full. Another responsibility of the municipality was the transportation of these containers to the disposal site by its own trucks. There were two trucks; their crew included three drivers and four assistants.

A major problem in the SWM of that time was the general shortage of containers. One of the main reasons was limited space availability, which also led to the selection of inappropriate container locations (e.g. far away from densely populated areas). The container shortage combined with insufficiently frequent emptying resulted in the containers being regularly overfilled, despite the presence of guards. Some containers in the city centre needed emptying twice per day – a service the municipality could not provide. As a consequence, the people started disposing their waste in open areas which had negative impact on public health, the environment and the aesthetics of the city. In addition, the municipality had no legal ground to collect a SWM fee from residents for waste transportation and disposal, so the budget had to be obtained from other sources of tax (Kassa, 2009). SWM was a very big financial burden for the municipality (Getahun, 2011).

In 2008, a group of young business men and women approached the municipality of Bahir Dar with a proposal to establish a private waste collection company aimed at improving the SWM in Bahir Dar: Dream Light Solid Waste Cleaning and Recycling PLC (abbreviated as DL). Their initial objectives were given the following priorities: first to clean up the city by installing an effective waste collection system and as a side effect create job employments, secondly to generate revenue from the waste through recycling activities and thirdly to improve the environmental conditions of the city and surroundings (Alemnew, 2011). The municipality welcomed Dream Light's entering into the solid waste sector as it acknowledged the problems with the waste collection system prevailing at the time. As cooperation between public and private sector was a novelty, different obstacles had to be overcome before Dream Light could be established by its 13 founding members in 2008. Raising the starting capital necessary to start the business was not possible through the bank as Dream Light could not provide any financial guarantees (lack of collaterals). In addition, there was no law that allowed the government to give a loan to private companies. Finally and because they were convinced of the benefits of establishing Dream Light, the Regional Government agreed to take the risk and gave Dream Light a loan of 2.4 Million ETB (without interest) for the start-up of the business. It was also the Regional Government that acquired the waste collection trucks in their name and leased them to Dream Light (explaining the '4' on the number plates implying that they are in fact registered as governmental vehicles). All this was possible because the justice bureau within the Regional Government as one of the decision-making parties in the discussions supported the idea (Alemnew, 2011). Due to the advanced waste management system in Bahir Dar (public-private partnership), in 2009 the city was selected by the NGO Forum for Environment Ethiopia to develop and implement an Integrated Sustainable Waste Management (ISWM) Plan for Bahir Dar with financial support of the United Nations Development Programme (UNDP).

The main development driver for both the municipality to outsource the collection services and for Dream Light to enter the SWM sector was concern of public health due to uncollected waste, followed by environmental concerns (Alemnew, 2011; Getahun, 2011). An additional important driving force was their fear that the uncollected and indiscriminately disposed waste would adversely affect tourism, which is the most important source of income for the city and thus crucial for the general development of Bahir Dar. As stated in UNEP (2010c), the vision of the City Administration of Bahir Dar is *"A clean and healthy city which is an economically dynamic and globally competitive tourist destination"*.
The interest of the municipality in improving the environment is mainly limited to presenting an attractive living environment. The hidden environmental damages (as caused for example by the dumpsite and the open disposal of human excrement) do not yet receive as much attention as beautification of the roadsides and parks by planted flowers (Fenzie, 2011).

To conclude from the conducted interviews, the initial driver for the current SWM was the reduction of risk to human health which by now has been largely fulfilled: As a consequence of Dream Light's newly introduced door-to-door collection system, the collection rate went up from 51% in 2005 (UNEP, 2010a) to currently 71% in 2010 (UNEP, 2010b). Current attention of DL has shifted to resource recovery i.e. to valorize the wastes through recycling activities. As for the municipal authorities, it has been mentioned by CA and BoEPLAU, that upgrading the current dumpsite to a sanitary landfill will be their next target on the way to move towards a more sustainable waste management system (Getahun & Fenzie, 2011).

4.2.2 Stakeholders (WHO?)

The main stakeholders in the MSW system in Bahir Dar include:

- **GOVERNMENT & UNDP**

1a) Bahir Dar City Administration (CA): The department 'Sanitation, Beautification and Park Development Core Process' (SBPD) within the CA is responsible for SWM in Bahir Dar including financing, recycling (e.g. compost production), disposal management, control and monitoring (UNEP, 2010b). SBPD has four sub-departments: 1) Sanitation 2) Park Development 3) Material Supply and 4) Human Resources. The main objectives of SBPD according to Getahun, head of office since January 2011, are to ensure sound sanitation (sanitation and urban solid waste), work towards further beautification of the city and to control and administer existing and new parks. The SBPD currently counts 24 permanent staff members (including technical and office workers), whereas 171 contract workers (including 85 street sweepers) are employed. Other core processes besides SBPD are 'Construction Core Process', 'Enforcing law and Protection of Illegal Activities' and 'Land Use and Administration' (Getahun, 2011).

1b) Regional Amhara Bureau of Environmental Protection, Land Administration and Use (BoEPLAU): The BoEPLAU has two main departments: 1) Land administration and land use planning core process, 2) Ensuring sustainable environmental protection core process, often abbreviated as EPA (Environmental Protection Authority). Within EPA, there are 3 sub-departments: a) Environmental Impact Assessment (EIA), b) Environmental Education and awareness rising, and c) Environmental standards. According to the head of EPA Melisachew Fenzie, the tasks of EPA is to prepare and produce legal rules, regulations and background for environmental proclamations, standards and directives and in addition also to conduct monitoring, auditing and inspection. EPA is sector-neutral, as it regulates not only the private sector but also governmental activities (Fenzie, 2011).

1c) Regional Amhara Health Bureau (BoH): This office has the right to provide guidelines, technical and professional advice in the field of health related issues. Their responsibilities include inspecting management of healthcare waste and controlling the sanitary conditions of public service centers like hotels and restaurants to ensure that handling and disposal of solid and liquid wastes are not harmful to public health. The office within the Regional Health Bureau responsible for health issues around SWM is named 'Waste Management and Environmental Pollution'.

1d) Regional Amhara Government: Its main responsibility is to coordinate the different regional bureaus and their activities. It functions as link between the Federal Government and municipalities and thus exerts direct influence on the City Administration. It was the Regional Government that in 2008 agreed to take the risk by giving Dream Light a loan of 2.4 Mio ETB.

1e) United Nations Development Programme (UNDP): UNDP is the funding agency for Dream Light's organic recycling projects. It has given Dream Light a loan of 1.6 Mio ETB with a payback period of four years. The main focus of UNDP is not solid waste management, but private-public partnerships that lead to good development in an integrated manner. One of the 'growth development packages' is solid waste management; their current focus is on enabling development by activities which protect the environment.

1f) Federal Environmental Protection Authority (EPA): The Federal EPA observes the developments in SWM in Bahir Dar as it sees the city as a demonstrational site and wants to scale up the recycling experiences there. In order to avoid monopolization of the SWM in Bahir Dar by Dream Light, the Federal EPA provided 600'000 ETB for the foundation of the CBO Green Dream as additional stakeholder for waste collection in one kebele of Bahir Dar. The money went through the Regional EPA to the City Administration and from there to Green Dream. The non-objection letter issued by the federal EPA to the UNDP enabled the construction of Dream Light's Organic Recycling Center.

- **SERVICE PROVIDERS**

2a) Dream Light (DL): DL is a private company responsible for collection, transportation, disposal and recycling of municipal solid waste in 8 out of 9 kebeles of Bahir Dar. The company structure of DL can be found in Appendix V. There are between one and three assigned DL-controllers (group leaders) per kebele depending on the size of the kebele. These controllers organize and supervise their collection team of 10-30 DL-workers who pick up the waste bags from the waste generators by push-carts or hand. The number of Dream Light waste collectors fluctuates between 180 and 230. Currently, DL staff is comprised of: Administration: 15, controllers: 18, waste collectors: 200, cash collectors: 20, truck drivers: 7, guards: 6 (Alemnew, 2011).

2b) Green Dream (GD): This Community Based Organization (CBO) is comprised of 30 female workers and responsible for solid waste collection in a door-to-door manner in one kebele (Shumabo). Initially Green Dream has received financial and technical assistances from the CA and EPA, whose intention was to initiate competition in the solid waste market and to avoid monopolization by Dream Light. Green Dream has no means of transporting large amounts of wastes, so they provide the waste bags for Dream Light's trucks to be picked up and disposed of.

2c) Million & Guadenutshu (M&G): M&G is a small business group (Million and his 55 workers) responsible for parts of the street sweeping and institutional sanitation activities (emptying of septic tanks) in Bahir Dar. The municipality has outsourced street sweeping activities of 6 km roads mainly in the city centre (out of a total of 35km asphalt roads in the city) by signing a 1-year contract a year ago. In a recently conducted bidding-competition, a new business group (Masfen) outcompeted the other competitors and hence will be responsible for street sweeping for the next year (Getahun, 2011).

2d) Informal recyclers*:*

- Koralews are informal itinerant buyers going from door to door to collect recyclable and reusable materials such as metals, plastics, glasses, corrugated iron sheets, tins, car batteries and others. They *buy* these materials and *sell* them to one of the 55 middlemen. 70 Koralews are working in Bahir Dar (Worku, 2012).
- Lewaches are persons going from door to door to *exchange* recyclable materials especially clothes and shoes for new plastic barrels, sauce panels, spoons, etc depending on the type and oldness of the cloth. 50 Lewaches are working in Bahir Dar (Worku, 2012).
- Dumpsite pickers collect recyclables & reusable materials from the disposal site and sell it to either middlemen or Dream Light PLC. There are 10-15 dumpsite pickers at Gordma working every day except Sundays (Worku, 2012).
- Children and beggars living on the streets go around from door-to-door and ask for food leftovers, reusable textiles and recyclable materials that they use themselves or sell to middlemen. Many Ethiopians give away materials to the poor due to religious considerations (Worku, 2012).
- Pig farmers: There are two pig farmers located in the north-east of Bahir Dar city centre. Around 550 pigs live in the larger one, while the smaller farm counts about 100 pigs. Both farms have workers going around the city with mule-pulled carts to pick up for free a total amount of 2.5 t/day of kitchen waste from hotels, restaurants and the universities.

2e) Formal recyclers:
Middlemen: Parts of the recyclable materials collected by koralews, lewaches, street persons and formal waste collectors are sold to middlemen, who in turn sell them to brokers of recycling companies in Addis Ababa. There are 55 middlemen collecting and selling metals, plastics and glasses and 1 middleman for textiles and shoes (Worku, 2012). These middlemen are registered at the Bureau of Trade and Industry, thus have a license for trading materials and need to pay taxes.

Δ WASTE GENERATORS & CIVIL SOCIETY

3a) Households: Bahir Dar has roughly 80’000 households (extrapolation based on CSA, 2007). They are responsible for filling their solid waste in collection bags and for payment of the service fees. The community in each kebele has the right to elect a kebele council. However, these kebele councils have very limited power in comparison to the City Administration.

3b) Commercials: The business sector which includes shops, hotels, restaurants, markets, garages etc. counts 7’040 commercials (UNEP, 2010a). They are responsible for filling their solid waste in collection bags and for payment of the service fees.

3c) Institutions: Institutions include governmental and non-governmental bureaus, schools, universities, colleges, training centers, prisons, churches, mosques etc. They are responsible for filling their solid waste in collection bags and for paying the service fee.

3d) Bahir Dar University (BDU): There are two campuses of BDU, the polytechnic institute (POLY, roughly 15’000 students) and the Pedagogic Institute (PEDA, roughly 30’000 students). BDU is involved in research and study work related to SWM in Bahir Dar (Mekete, Atikilt & Hana, 2009) and has participated in the development of the ISWM Plan.

3e) Forum for Environment (FfE): This NGO is actively participating in raising environmental awareness and has initiated the development of an integrated sustainable waste management plan for Bahir Dar. FfE Bahir Dar has one paid employee (secretary) and 40 members with different backgrounds.

There is no specific formal structure/platform (committee, regular meetings or specific person within the municipality) for communication of stakeholders. In case of particular matters, the stakeholders contact each other informally mainly per phone (Alemnew, 2011; Fenzie, 2011; Getahun, 2011).

In order to get an overview of the different stakeholders in SWM, a power-interest matrix is used as a helpful tool. For that purpose, different persons were asked to rate the *power* (the extent to which they are able to persuade or coerce others into making certain decision or following certain courses of action) of SWM stakeholders in Bahir Dar and also their *interest* (the extent to which SWM is given priority). The following persons (as representative of their respective organization) were asked to rate *power* and *interest* of each stakeholder separately on a scale from 1 (= very low) to 10 (very high):

- Getahun, Zelalem (CA)
  City Administration, Head of Sanitation, Beautification and Park Development Core Process
- Alemnew, Getachew (DL)
  Dream Light PLC, Head of Marketing and Sales Department
- Fenzie, Melisachew (EPA)
  Regional BoEPLAU, Head of Ensuring Sustainable Environmental Protection Core Process
- Atnafu, Biazn (FfE)
  NGO Forum for Environment Bahir Dar, Coordinator and secretary
- Zemadin, Birhanu (BDU)
  Bahir Dar University, Professor for Civil and Water Engineering, expert in SWM

The average ratings are presented in Figure 6, for details of the individually given scores, see Appendix VI.

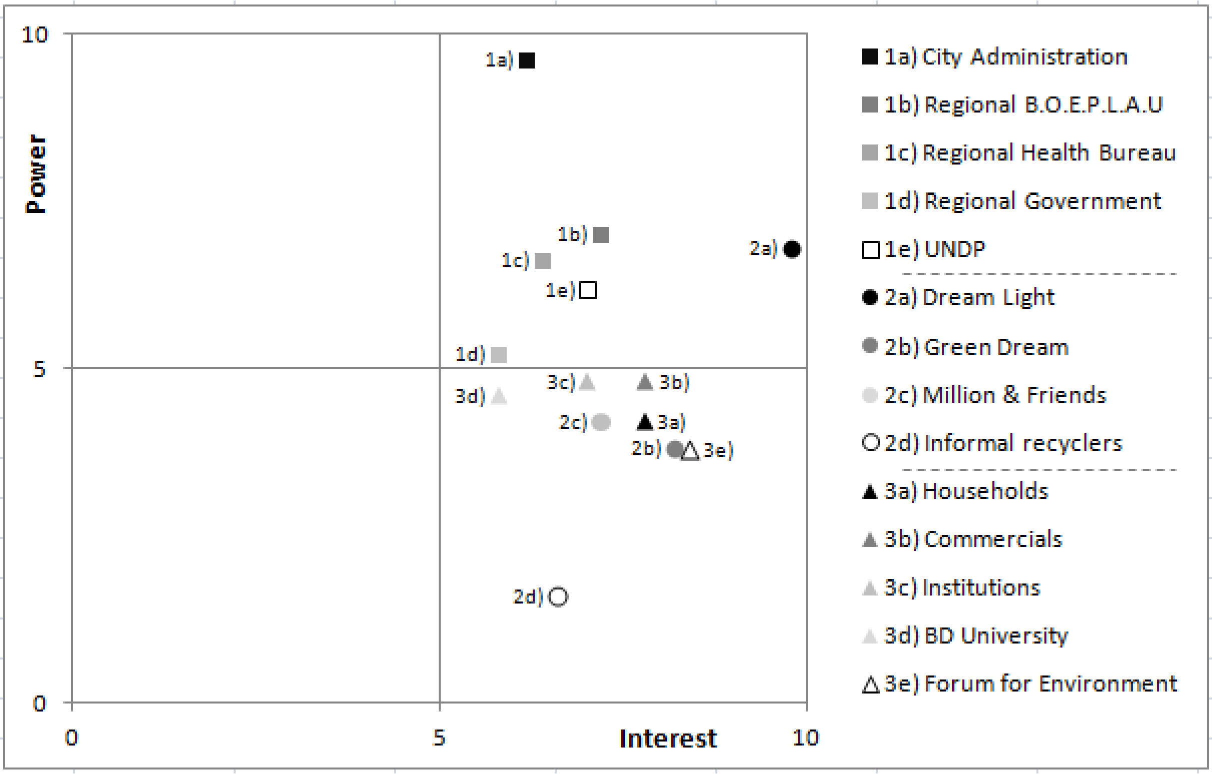


Figure 6: Power-interest matrix of SWM-stakeholders in Bahir Dar

The power-interest matrix presented above illustrates that the municipality (City Administration) has the highest power in the current SWM system, whereas highest interest is allocated to Dream Light. Regional Health Bureau, UNDP and institutions are also located in the quadrant of high power and high interest; all other stakeholders are positioned in the low power and high interest quadrant. A potentially disruptive constellation would be if a powerful stakeholder has low interest in the SWM system. Based on the interviews and the resulting matrix depicted above, this is not the case in Bahir Dar.

4.2.3 Components of physical system (WHAT?)

The following sub-section describes the physical components of the solid waste system in Bahir Dar. It is divided into four parts: Generation, collection & transport, resource recovery, and disposal.

The Federal SWM Proclamation No. 513 (2007) defines Solid Waste and SWM as follows: 'Solid Waste' implies anything that is neither liquid nor gas and is discarded as unwanted. 'Solid Waste Management' means the collection, transportation, storage, recycling or disposal of solid waste, or the subsequent use of a disposal site that is no longer operational. The term 'Municipal Solid Waste' (MSW) covers solid wastes generated by households, by commercial and industrial premises like shops, hotels, garages and agriculture, by institutions such as schools, hospital care homes and prisons and from public spaces such as streets, bus stops, parks and gardens (Scheinberg, Wilson & Rodić, 2010). According to Getahun (CA, 2011) and Fenzie (EPA, 2011), these are the definitions used by the municipality and the majority of stakeholders in Bahir Dar.

- **Waste generation: Sources, quantities and composition**

As part of the UNEP project for the development of an ISWM Plan for Bahir Dar, the solid waste was characterized and quantified in 2010. Random sampling method was applied and the number of samples determined by using a (low) confidence level of 80%. For analysis of the residential waste stream, samples from 8 randomly selected households at 31 different neighbourhoods (= total of 248 households) were taken one time when households put out their waste bags for weekly collection services (hence containing mixed waste from 7 consecutive days). The wastes of the 8 household were collected, mixed and reduced three times to get a sample with average composition.
For analysis of the commercial waste streams, samples were taken from 8 commercial centers at 34 different sources (= total of 272 commercials). For street-sweeping a sample was taken from 1/8 of 1km street waste. All together 108 samples were taken and sorted by hand. The Total Solids (TS) content was further analyzed (UNEP, 2010a).

The daily generation of MSW in Bahir Dar amounts to a total of **102.5t/d**. UNEP (2010a) lists a total of 98.8t/d due to a mistake (UNEP 2010a, p.25, table 13: commercial waste 24.2 t/d instead of 28 t/d as calculated on p.24). After being confronted with it, Getnet Hunegnaw (at the time of the UNEP study working for the Reg. EPA and responsible for waste characterization and quantification) recognized this error (Hunegnaw, 2011). The main share (54t/d) originates from residential sources. Figure 7 reveals the MSW sources in Bahir Dar and their percentage of the total waste.

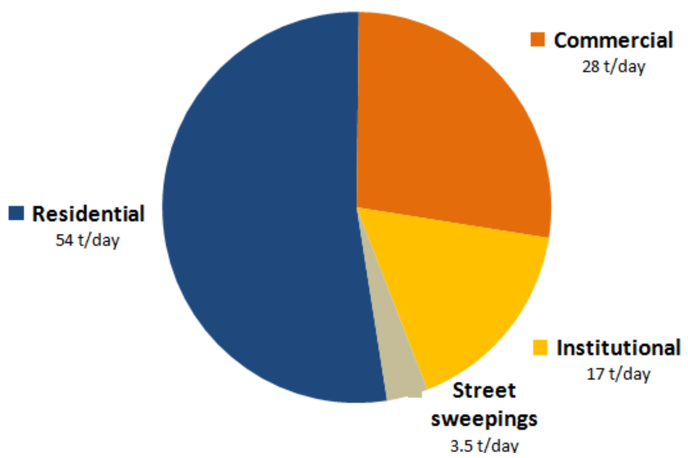
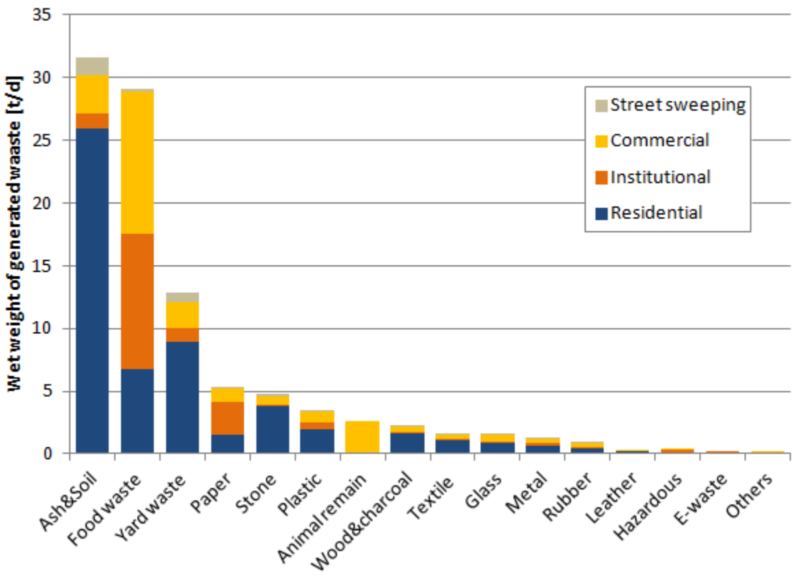


Figure 7: Sources of MSW in Bahir Dar (based on data from UNEP, 2010a)

Figure 8 presents an overview of the composition of total municipal solid waste in Bahir Dar and depicts the origins of the waste material fractions. 32% of the total MSW consists of ash and soil, 30% is food waste and 13% is made up of yard waste. The large share of ash & soil component in residential waste (47%) is explained by the predominant use of firewood and charcoal in households (see Appendix IV). The ash residues are usually disposed on the ground, later put in the waste collection bag from where it is collected by Dream Light workers. The seasonal variation is expected to be minimal due to steady consumption behavior throughout the year (Alemnew, 2011).



Per capita generation of waste in Bahir Dar was assessed to be 0.25 kg/day for residential and 0.45 kg/day for all residential, commercial, institutional and street sweeping waste streams (UNEP, 2010a). The waste projections by UNEP (2010a) show that the waste generation will increase similar to the population growth. Hence in 2021, when the population is doubled, waste generation will also be doubled (199t/day).

Figure 8: MSW streams in BD and their compositions as wet weight (based on data from UNEP, 2010a)

Organic waste

UNEP (2010a) classifies yard waste, food waste and ash & soil as organic components, although the ash & soil category most likely contains a considerable amount of inorganic impurities. When asked about the reasons for counting ash & soil as organic components, Getnet Hunegnaw (Regional EPA, involved in UNEP study) explained that this is a mistake and the category of soil & ash should not be counted as organic waste. His explanation was that although EPA advised differently, Dream Light workers on some occasions acted independently during the waste qualification and quantification procedure and considered ash & soil as organic waste, probably due the possibility of bringing it back to the soil for agricultural purposes (Hunegnaw, 2011).

Based on the share of organic content (food and yard wastes) in the different waste sources (UNEP, 2010a) the sum of food and yard wastes from the residential (16 t/d), commercial (16 t/d), institutional (12 t/d) and street sweeping waste streams (1t/d) results in a total organic waste quantity of 45 tons per day, which equals 44% of the total amount of daily generated waste in Bahir Dar.
This differs substantially from the total organic waste according to UNEP (2010a) which is 73.7 t/d (or 74.6%) because of the above mentioned mistake. The present thesis does not count ash & soil as organic component because it can neither be used as substrate for anaerobic digestion, nor for composting or bio-briquetting.

Hazardous waste

According to UNEP (2010a), hazardous waste of Bahir Dar City includes:

- Wastes from hospitals and medical laboratories
- Chemicals: chemically contaminated containers and trimmings from agriculture, pesticide retailer shops, university and school laboratories, tanneries, textiles and expired drugs
- Biological wastes from hospitals and biological research facilities
- Dry cell from each sources and car batteries from garages
- Used condoms from hotels and pensions
- Fluorescent lamps

Residential hazardous waste amounts to 156.6 kg/d (0.3% of total residential waste stream), commercial hazardous waste was recorded to be 124.8 kg/d (0.5% of commercial waste). Institutional hazardous waste was 120.7 kg/d (0.7%) and street sweeping hazardous waste was 0. This makes a total of 402.1kg of hazardous waste generated per day, which is 0.4 % of the total MSW in Bahir Dar (UNEP, 2010a).

- **Waste collection & transport**

Since Dream Light's entry into the SWM system of Bahir Dar in 2008, it is the waste generators responsibility to put their mixed waste into any (non-standardized) bags and place them in a designated location on their compound or along the road. From there the waste collectors - Dream Light workers in 8 kebeles, Green Dream workers in 1 kebele - can easily collect them in a door-to-door manner (filling the waste in their 50 kg plastic bags). Residential waste is collected once per week, while the frequency of collection from commercial centers depends on the contract agreement between them and Dream Light. Some high-standard hotels require having their wastes collected up to twice per day. There are 1-3 controllers/group leaders per kebele, depending on the size of the kebele. These controllers organize and supervise their collection team of 10-30 workers who empty the generators waste bags into push-carts or into strong plastic bags (50 kg, second hand bags previously used for agricultural fertilizer) and bring them to collection points. There are 17 push-carts in total, only used in large kebeles where distances between waste generators and collection points are long. The waste collectors are equipped with overalls, plastic gloves and most of them cover their mouth/nose with a thin scarf while handling the waste.
The CBO 'Green Dream' is responsible for solid waste collection in one kebele (Shimabo). Around 30 workers, exclusively women, perform door-to-door collection and put the solid wastes in strong 50 kg plastic bags that they dispose on the designated collection points. There, the workers await the Dream Light collection truck to empty the bag contents. The emptied bags are hung up for drying and re-used.

Figure 9: Waste bags on the street; door-to-door collection service with push carts; unofficial collection point; emptying waste bags on collection truck (left to right)

In the UNEP study an overall collection rate of 71% is stated, which is 73 tons/day from a total of 102.5 t/day generated. The remaining amount of 29.5 t/d is not being collected and according to UNEP (2010b) burned, buried or simply dumped on the lakesides or into rivers.
Some parts of the street sweeping (6 km from the total 35 km of streets) are outsourced to a small and micro business groups called 'Million & Guadenutshu' (Million and Friends), the remaining streets are swept by the city service itself. The street sweeping workers fill the street waste into the 50 kg plastic bags and leave them along the streets from where they are picked up by Dream Light or Green Dream workers.
There are no officially designated waste collection locations in Bahir Dar, but around 100 widely accepted collection points on the side of the road. These semi-official collection points were selected using the following two main criteria: 1) Easy accessibility with pushcarts, workers and especially collection trucks and 2) 'Acceptable' distance to residents (needs to be negotiated in each case separately with the nearby residents) in order to avoid complaints due to odor and aesthetics.

Dream Light has a fleet of 7 low-skip 'Forland' collection trucks (bought second-hand from China), each with a capacity of $4m^3$. An average of 6 trucks are operational and regularly in use. According to a scheduled order, they drive to the collection points where the waste collectors await them and after their arrival empty the mixed content of the 50 kg bags on the truck. The emptied bags are hung up on fences to dry in the sun so that they can be reused. When the loading space of the truck is filled, it is covered and fixed using a plastic sheet. Each truck is filled and, according to the truck drivers, emptied approximately 8 times per day at the disposal site. Thus Dream Light collects, transports and disposes around $192m^3$ of solid waste per day from different sources. As one meter cube of municipal solid waste weighs approximately 375 kg (Kassa, 2009) this is equivalent to 72 tons of waste being brought to the dumpsite per day.

- **Resource recovery**

According to UNEP (2010b), recycling of solid waste in Bahir Dar is with less than 1% insignificant. The reason for this statement lays in the fact that the UNEP study only accounted municipal composting as recycling activity and did not include informal recycling activities. Dream Light started selling used paper to paper recycling industries and also advises its workers to separate plastic waste from the mixed municipal waste stream. Dream Light pays 2ETB/kg for hard plastic and 1ETB/kg for soft plastic and later on sells the plastic to recycling companies in Addis Ababa for 5 ETB/kg. There are koralews, lewaches and street persons who collect some recyclable goods and reuse, resale or recycle it at small scale level.

Organic recycling is currently practiced as follows:

- Municipal composting site: The idea behind its initiation in 2003 was to produce compost for plants in the city centre. The municipal composting site is located 3km south of the city and currently employs 7 workers. An 8m^3 waste container, placed next to the vegetable market of Bahir Dar, is filled by the vegetable sellers. Municipal workers transport the filled container by truck to the composting site about once per week. Thus 8m^3 (3t) of fresh substrate arrives approximately 4 times per month, where it is manually sorted, turned and decreased in size. After 3-4 months, the finished compost is picked up by the municipality and brought to the city to be used for planting of flowers (city beautification). During two months of the rainy season (July, August), no composting activities take place.

Figure 10: Municipal composting: Biowaste container in market, composting cite, crushing of compost (left to right)

- Pig farmers: Two private pig farms are located in the north-east of Bahir Dar close to the Blue Nile River. The larger one has 500-550 pigs and collects a daily amount of 2-2.5t of kitchen waste from the city. The smaller one has 100-120 pigs and collects between 400-500kg/day also mainly from the two universities, restaurants and hotels.

- **Disposal**

According to UNEP (2010b), no treatment facilities exist in Bahir Dar. All healthcare and industries and some governmental institutions follow their own way of removal. Most of them burn their waste; while some others dispose it to the nearby river Blue Nile or into Lake Tana (UNEP, 2010c).

The open dumpsite Gordma has been established in 1998. It has a total area of 2’500m^2 and is located 3-4 km from the city center in southern direction. According to Kassa (2009), an ideal disposal site selection depends on considering several independent factors such as capacity (lifespan), land use, soil condition (water permeability), slope, depth of underground water table, distance from rivers, waste generation, residential areas and access to roads. However, in the case of Gordma there is no documented evidence that shows the criteria used for the selection of the area as dumpsite. Although there was no prior study regarding hydrology, geology, socio-economic and environmental issues, the open dumpsite fulfills a few of the above mentioned criteria like accessibility for road network, far from streams and rivers and a flat and low lying topography (Kassa, 2009). The dumpsite is surrounded by land use activities such as informal settlement and agricultural activities. The liquid human waste (from emptying of septic tanks in Bahir Dar) is also dumped in close proximity of Gordma.

The open dumpsite in Gordma is characterized by (see Figure 11):

- No entry gate
- No fencing and hence easy access for livestock and scavengers
- No daily (or any) cover and compaction of solid waste
- No separate cells for disposal of hazardous waste (indiscriminate dumping)
- No leachate management
- No groundwater monitoring and landfill gas management
- No formal working activities on dumpsite
- Frequent fire outbreak
- The surrounding farmlands and grazing lands are littered with plastics, paper and other materials blown by wind

Figure 11: Open dumpsite Gordma in Bahir Dar: Arrival and discharge of waste from collection truck, dumpsite pickers and scavenging animals

10-15 informal dumpsite pickers recover reusable and recycle materials like metals, glasses, plastic and textiles and sell it to middlemen or Dream Light (mainly plastic recyclables). A few dozens of dogs live on the dumpsite from the remains of dead animals being disposed there (road victims, slaughter waste from residents, restaurants and butchers).

In the year 2010 the total disposed waste was calculated to be 73 tons/day (UNEP 2010c).

4.2.4 Sustainability aspects (HOW?)

This sub-section provides an overview of the enabling environment for the municipal solid waste system in Bahir Dar. It combines the results from the document 'Assessment of the SWM system in Bahir Dar town and the gaps identified for the development of an ISWM plan' (UNEP, 2010b) with field observations and information gathered through interviews with SWM stakeholders.

- **Technical aspects**

  Collection & transport
  - No waste segregation is currently practiced at source, apart from the small-scale segregation of recyclables for informal recycling
  - There are no standard solid waste transfer stations in Bahir Dar. As the disposal site is close enough to the city (3-4 km), the existence of a transfer station is financially not justified.

- It is difficult to designate unofficial collection points for temporary storage of waste during collection. Although people living nearby complain about the odor or other nuisances (NIMBY), the City Administration sees it as the only alternative for the moment. These collection points are not allocated by the municipality but by Dream Light. In case of frequent complaints about the location of collection points, the City Administration intervenes and tries to find other collection points more distant from the residents.
- Solid waste collection (71%) does not cover all solid waste generators. Based on discussions with Dream Light, the following collection rates are roughly estimated respective to their source: 70% of the total waste generated in the households is collected, 80% from total generated in commercials, 50% from total generated waste in institutions and 70% of the total waste laying on the 35km of asphalt road.
- Transportation trucks are not standardized for solid waste transportation purposes, spare parts are not locally available - they have to be imported from the capital Addis Ababa.

Resource recovery
- No financial or technical support, no public recognition for waste recyclers
- Only a small amount of organic solid waste (0.5t/d) is used to produce compost in the municipal composting plant

Disposal
- There are no treatment facilities in Bahir Dar for MSW
- Open dumpsite (no sanitary landfill)
- No sound operation practices performed at disposal site: No designated cells, no machinery (compactor or graders)] working at disposal site
- 71% (73t/d) of generated MSW is collected and disposed of at disposal site

- **Environmental aspects**
  - Dumpsite Gordma is close to rural settlements and leads to pollution of groundwater sources through leachate (Worku, 2012).
  - 29% of generated waste (29.5t/d) is not collected by Dream Light or Green Dream. This waste is either burned or buried in compounds or disposed to lakesides or into rivers, leading to pollution of environmental compartments.

- **Socio-cultural aspects**
  - Participation in the current solid waste system needs to be differentiated into the following two parts: Participation required at the source of waste generation (collecting waste, putting it into bags and in the designated place to be picked up) is considered to be good, particularly considering the short time since the introduction of this new system. However, payment rate of collection fee is low (around 50%) thus considered as poor (UNEP 2010b).
  - Awareness of public towards SWM is still considered to be low, although it has increased considerably in the last two years. When Dream Light started its business, it organized awareness raising campaigns to teach people how to handle waste. Its managers also participated to demonstrate that touching waste is neither dangerous nor despising (Alemnew, 2011).
  - It took about one year until the waste collectors started being fairly recognized for their contribution to a clean city.
  - The working condition for waste collectors is acceptable but needs to be improved: The protection clothes (overall, gloves) are replaced by Dream Light twice per year only at pre-set dates. This means that workers have to continue working with damaged equipment until then.
  - The salary for waste collectors (400 ETB/month) classifies the work as a low-income job, yet Dream Light considers most workers to be grateful having an income generating opportunity at all. The salary is comparable to the salary of a waiter in a good middle-class hotel in Bahir Dar or of a guard working for a private company. In comparison, the controllers (group leaders of waste collectors) receive 800 ETB/month.
  - Dream Light explicitly offers their waste collecting jobs to street persons, prostitutes and other underprivileged members of the society.

- **Financial-economic aspects**
  - The payment rate for the solid waste collection service has been low until now: Only about 50% of the households pay the collection fee. About 90% of the commercials and institutions receiving waste collection services pay the fee regularly. This is on one hand due to the individual agreements Dream Light worked out with them, on the other hand the hotels, restaurants, shops etc. are depending on a clean environment for the satisfaction of their guests and customers.
  - As a result of the low payment rate of households, a committee comprised of different stakeholders, including City Administration, EPA, hotel association, and Dream Light, worked for three months on the development of an improved payment system. In the old system, each household was required to pay a monthly fee of 15 ETB to Dream Light's fee collectors who went from door-to-door to collect the fee in cash. Commercials and institutions had individual agreements with Dream Light based on the waste quantity and frequency of collection/disposal.
  - The new system follows the idea of the system practiced in Addis Ababa. It is based on the assumption that the water consumption correlates with waste generation i.e. a household that consumes high amounts of fresh water also generates high quantities of solid waste. Thus the payment for water and for waste collection will be linked. This new system is possible due to the fact that all households in Bahir Dar have a water meter installed on their compound and each household is responsible to go to the Regional Bureau of Water supply once per month to pay the monthly water bill. The new progressive system is divided in 4 progressive categories depending on the amount of fresh water consumed per month:

Table 7: New payment system for solid waste collection in Bahir Dar

Category	Water consumption per month	Solid waste collection fee per month
1	0 – 5 m^3	3 ETB / m^3 of consumed water
2	5 – 10 m^3	4 ETB / m^3 of consumed water
3	10 – 25 m^3	6.2 ETB / m^3 of consumed water
4	> 25 m^3	8.2 ETB / m^3 of consumed water

  - As an example: A four-member family that consumes 40L of fresh water per person per day will have to go to the water supply department and pay a monthly fee for waste collection of 14.4 ETB (4'800 L water/month → 4.8 * 3 ETB = 14.4 ETB)
  - The City Council has approved this new system and it was planned to put it into practice in September 2011. The reason that it has not yet been implemented is the result of software problems in the billing system (Alemnew, 2011)
  - It is the responsibility of the City Administration to inform the citizens of Bahir Dar about the new system. Despite the appearances of municipal officials in kebele councils, radio and TV, the majority of the inhabitants are not yet aware of this new payment system, which was intended to be introduced in September 2011 (Getahun, 2011).
  - City Administration and Dream Light do not expect major protests due to the implementation of the new payment system. However, special agreement will have to be arranged with recreational facilities like public swimming-pools (which consume a disproportionately high amount of water).
  - The main advantage of the new system is the leverage in case of non-payment: The water supply can be cut if the residents fail to pay the combined costs for water supply and waste collection (for payment of the water bill, the residents have to appear once per month at the Regional Bureau of Water Supply).
  - In addition, institutions that until now mismanaged (burned, buried, openly disposed) their waste by themselves will most likely use DL's collection service as they have to pay for it anyway.
  - With the new payment system Dream Light expects to be able to cover all their expenses related to collection services (440'000 ETB/month).
  - Until now, Dream Light's business was economically not sustainable. Thus the loan of 1.6 Mio ETB UNDP provided for 4 years is not only meant to cover the expenses for the Organic Recycling Centre, but also to cover the current running costs for waste collection.

- **Institutional aspects**
  - Integration and coordination of the current institutional arrangement of the SWM is unsatisfactory: Each sector is working independently (UNEP, 2010b)
  - There is no clear bridge between the federal (national) institutions and the regional (or local) institutions. The federal institutions aim at building up capacities by giving much responsibility to the Regional institutions and thus the Federal Government supports Regional Governments only financially. However, due to institutional problems at regional level, gaps occur. The Regional EPA for instance has the responsibility to translate the Federal SWM Proclamation (2007) into a regional one. But apparently there are problems delaying the completion of this task and hence there is not one regional Proclamation that deals with SWM in Amhara state. Therefore it is the Federal SWM Proclamation that counts, but since it does not contain clear allocation of responsibilities on local level, it is hardly enforced (Alemnew, 2011).
  - The City Administration (SBPD) who has outsourced waste collection, transport, treatment and disposal services to Dream Light is responsible for monitoring these activities. In their opinion, this supervision is good as they have assigned specialists to control Dream Light's field works according to a check list. However, Dream Light regards the collaboration in terms of monitoring to be insufficient: They believe that the monthly reports they have to submit to the City Administration are sometimes not even read and surely never cross-checked (all numbers provided are always accepted). There were complaints from Dream Light's side that many members of the City Administration are not informed at all about Dream Light's activities. A closer collaboration would be appreciated to steer the SWM into a more sustainable direction. As a result of the loose collaboration between CA and DL, misunderstandings occur: While the CA looks at waste collection service as a good business and initiates steps towards breaking Dream Light's monopolization of the SWM system by establishing Green Dream, Dream Light feels another approach would have been more effective: To enable fair competition within the market instead of supporting small associations financially and logistically. CA on the other hand considers this to be fair because it has also supported DL in the beginning in similar ways (e.g. by finding ways on how to provide a loan for Dream Light and how to purchase vehicles for them).
  - The Regional Bureau of Health as well as the Regional EPA expressed their pity that their advices regarding hazardous waste handling, official collection points/transfer stations and upgrading of the current open dumpsite are not taken seriously by the City Administration.
  - In general, the cooperation of stakeholders is described by the majority as very loose (rather than conflicting) and leaves considerable room for improvements in the future.

- **Policy & legal aspects**
  - The region has not yet enacted any law on environmental issues. It is rather using the federal laws but facing difficulty in implementation, enforcement and monitoring.
  - The regulation of hygiene and environmental sanitation of the Amhara National Regional State adopted in 2002 was until 2010 the relevant document for SWM in Bahir Dar. It was recently canceled as the Federal Government enacted a new National Proclamation (No. 661/2009 Food, Medicine and Health Care Proclamation), which yet has to be translated into a Regional Proclamation (Mengistayehu, 2011). The Federal SWM Proclamation 513/2007 is valid on country-level.
  - Bahir Dar does not have its own detailed rules and regulations specific to SWM that clearly indicates the responsibilities of the actors involved in SWM. There are no clear rules and regulations pertaining to SWM apart from general guidelines, an approach which is not effective at all (Kassa, 2009).

4.2.5 Process Flow Diagram

Figure 12 presents the process flows in the MSW system of Bahir Dar. The current system is quite complex with many different formal and informal service providers and can be described as early state of modernization. The strongest driver has been protection of public health by providing proper collection services. It is only recently slowly shifting towards valorization of resources (recycling project of Dream Light), whereas environmental protection concerns are predicted to be tackled at a later stage.

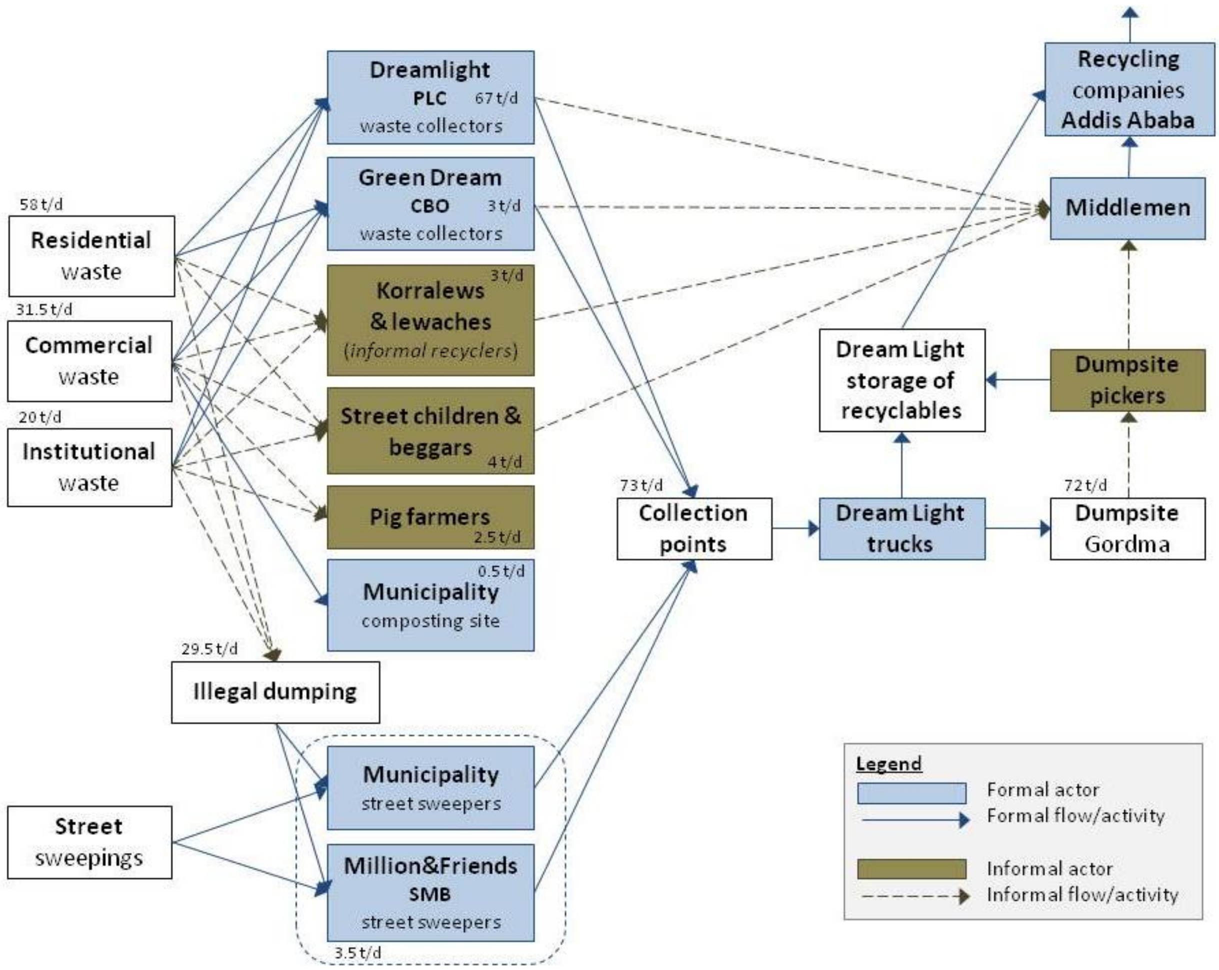


Figure 12: Process Flow Diagram of the municipal solid waste system in Bahir Dar

4.2.6 Dream Light's Integrated Organic Recycling Centre

As introduced in 4.2.1 and 4.2.2, Dream Light Solid Waste Cleaning and Recycling PLC (short: Dream Light) is an Ethiopian based private company established in 2008, providing waste management services and recycled products for the residents of Bahir Dar.

The following statements are taken from the Dream Light brochure (Dream Light, 2011):

Vision Being the best waste management company in Ethiopia and in Africa region.

Mission Raising our self by serving our community

Objective
- Maximize our profit by implementing standard waste management & recycling systems
- Create clean and attractive living environment in the city
- Create job opportunity to women and youth community members
- Reduce the environmental effect of waste by recycling and producing reusable products

Activities - Waste collecting, transporting and disposal service
- Recycling some wastes to reusable materials like biogas, bio briquette and compost
- Sorting and reselling plastics and paper wastes to recycling companies
- Building small scale biogas plants and compost pits
- Giving training about waste management and environmental protection to community
- Developing integrated plans like integrated waste management plans and spreading knowledge and experiences to different cities

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Dream Light participated in the development of an ISWM Plan for Bahir Dar (UNEP, 2010a/b/c). In order to valorize parts of the collected (organic) waste, an Integrated Organic Recycling Centre has been planned, designed and constructed by the contracted company ThiGro Power Co-operative. ThiGro Power is an Addis Ababa based company that has been established in 2009 and works on alternative renewable energy and related sectors. 'Integrated' means that three different recycling/valorization technologies are built for parts of the organic municipal waste: 1. Charcoal briquetting system, 2. Anaerobic Digestion system, and 3.Composting system

All three technologies are first briefly described in general and then the technological set-up in the Organic Recycling Centre is explained as proposed by ThiGro Power:

<u>1. Charcoal briquetting system</u>
Briquetting is the process of converting low bulk density biomass into high density and energy concentrated fuel briquettes (Sugumaran & Seshadri, 2010). Charcoal briquettes (in Bahir Dar named bio briquettes) are fuel pellets of higher energy content produced from material that has either been carbonised prior to its compaction, or compacted first and then carbonised. Either way, energy values of up to 30MJ/kg can be achieved, which puts some of these briquettes on a par with regular lumpwood charcoal in terms of combustive quality (UNHR, 2002).

The briquetting process consists of the following steps (Demirbas, 2009; Sugumaran & Seshadri, 2010):

- Biomass collection: Agricultural, industrial or forest wastes can be used. In Bahir Dar, the first experiments are conducted with rice husks.
- Drying: Rice husks don't require additional drying, but a solar dryer will be purchased at a later stage to prepare wet agricultural waste (during rainy season).
- Carbonization: Conversion of organic substances into carbon or a carbon-containing residue through pyrolysis (thermochemical decomposition of organic material at elevated temperatures without the participation of oxygen). Thus charcoal is produced by slow heating of the substrate in airtight ovens or retorts, in chambers with various gases, or in kilns supplied with limited and controlled amounts of air. After the carbonization process, char powder (30-45% of the initial substrate weight) is produced; the char yield varies according to the biomass used.
- Preparation of char powder: The char powder is crushed (e.g. with a hammer mill) and passed through a variety of screens to reduce the particle size.
- Binder preparation and mixing: A binder and water is added to the carbonized char powder for strengthening of the briquettes. Different binders such as commercial starch, rice powder, rice starch (rice boiled water) and other cost-effective materials like clay soil can be used.
- Briquettes production: The mixture is pressed into a mold to form a cake or briquette
- Drying and packing: The briquettes are dried, packed and sold.

For Dream Light's Organic Recycling Centre (ORC) ThiGro Power designed the following set-up of briquetting system:

- 3 kilns (à 3m^3)
- 1 hammer mill (5.6 kW)
- 1 mixer (2 kW)
- 2 screw molding machines (5 kW)

Figure 13: Shed for charcoal briquetting in BD, left to right: preparing the footing for the machines; molding machines, mixer, hammer mill; kiln in shed; kiln during first try-out

Dream Light has an agreement with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) who guaranteed to buy the complete annual production of briquettes from the first year. GIZ intends to promote the sale of charcoal briquettes in combination to their improved stoves. With increased briquette production in the following year, the briquettes will be sold in Bahir Dar (Alemnew, 2011).

2. <u>Anaerobic Digestion system</u>

The theoretical background of anaerobic digestion is explained in chapter 5.

For Dream Light's Organic Recycling Centre ThiGro Power designed the following set-up of anaerobic digestion system:

- 1 fixed dome underground biogas digester (62.5 m^3), model SINIDU (see Figure 44 for design)

Figure 14: Construction of biogas digester (left two pictures by G.Alemnew)

Dream Light will use the biogas in the bakery (to be constructed next to the digester) in a hybrid oven. This hybrid oven runs with electricity or biogas and shall be able to bake 108 breads (à 100g) at a time. Parts of the liquid effluent (digestate) will be used for mixing of the compost to reduce the composting time from 4-6 month to 1 month (Dejene, 2011).

3. <u>Composting system</u>

Aerobic composting is the controlled bio-oxidative decomposition and stabilization of organic substrates in the presence of oxygen. The decomposition is carried out by successive microbial populations combining both mesophilic and thermophilic activities, leading to the production of CO_2, water, minerals and a stable, sanitized and humus-like material rich in organic matter and free of offensive odours that can be stored and applied to land without adverse environmental effects (Polprasert, 1996).

For Dream Light's Organic Recycling Centre ThiGro designed the following set-up of composting system:

- 1 composting site (150m^3)

Figure 15: Construction of composting pit (left picture by G.Alemnew)

The above described technological set-up represents the first stage of the Organic Recycling Centre. If successful, plans exist for an expansion stage, in which additional kilns, another composting pit (150m^3) and two new AD systems are planned.

Figure 16 presents a panorama picture of Dream Light's Organic Recycling Centre during construction.

Figure 16: Panorama view of Dream Light's Organic Recycling Centre (14.10.2011)

5 Anaerobic digestion (AD) of biowaste

5.1 History of anaerobic digestion for treatment of biowaste

Anaerobic digestion (AD) has traditionally been used to treat liquid wastes with or without suspended solids such as manure, sewage, industrial wastewater and sludge from biological or physic-chemical treatments. In comparison, solid wastes such as agricultural and municipal solid waste had attracted comparatively little attention from AD specialists until recently (Mata-Alvarez, 2003). However, due to their high organic matter content and consequent high potential for biogas production, interest in organic solid waste streams started increasing about 40 years ago. Researchers from the University of California in 1970 conducted some of the first studies on AD of solid waste, examining the technical feasibility of AD of MSW mixed with other wastes such as manure and sewage sludge. Subsequently, numerous articles were published devoted to AD of MSW. These articles focused on municipal waste before sorting and mainly addressed the problems of landfill biomethanization (Mata-Alvarez, 2003).

The beginning of the AD solid waste study in Europe took place in the 1980s and was dedicated directly to biowaste (Mata-Alvarez, 2003). De Baere (2006) argues that biological treatment was boosted by the introduction of source separated collection of a clean biodegradable fraction.

In recent decades, anaerobic digestion of biowaste has been studied intensively with the objective to develop a technology that offers waste stabilization with resources recovery (Nguyen, Kuruparan & Visvanthan, 2007). Major driving forces behind the development of anaerobic digestion technologies for biowaste in Europe have been limited landfill capacities with increasing tipping fees, subsequent legislation on progressive elimination of landfilling of organic waste (Landfill Directive, 1999) and recently introduced renewable energy laws trying to promote and facilitate sustainable energy production (Nichols, 2004). AD is nowadays considered to be an established and reliable technology in Europe and Asia, and is used to treat more than 10% of organic waste in several European countries (De Baere, 2000). Also on a worldwide scale, AD of biowaste has by now become an established biological treatment technology (Gebren & Oelofse, 2009). It is mainly the beneficial recovery of energy as well as the recovery of nutrients which make AD of biowaste a sustainable and appreciated treatment concept (Hartmann & Ahring, 2006).

5.2 Process chain of anaerobic digestion of biowaste

In order to analyze the AD process of biowaste, it is helpful to take a systemic supply chain perspective. According to Mentzer et al. (2001) supply chains are "*a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*". Supply chain coordination means that supply chain members work towards a unified system and coordinate with each other (Gold, 2011). The process chain of AD comprises the following three main components (Figure 17):

- Substrate chain: Waste generation, collection, transportation
- Transformation process: Pre-treatment of substrate, transformation of the waste into valuable products, post-treatment of products
- Product chain: Distribution, utilization

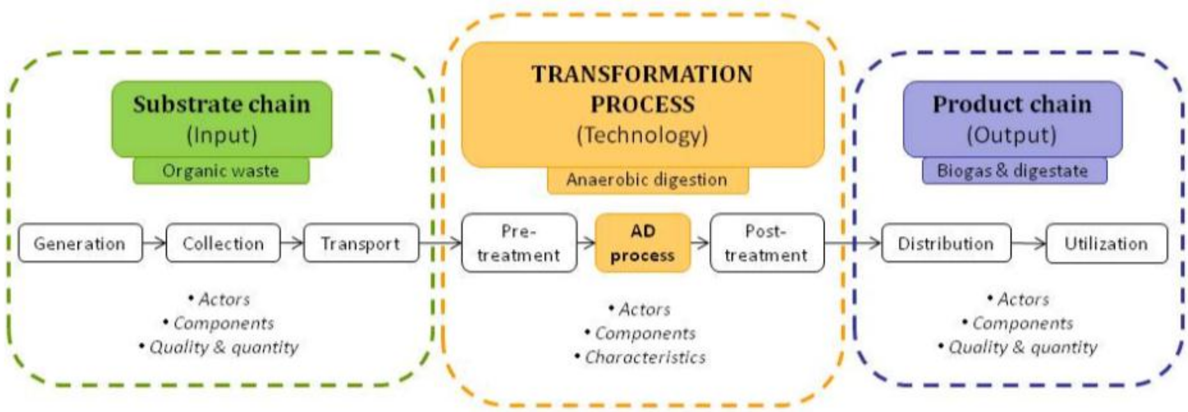


Figure 17: Process chain of AD for biowaste

Overall, the AD process chain of biowaste combines two systems, namely the solid waste (substrate) supply system and the bio-energy/-nutrient system (Ambulkar & Shekdar, 2004).

5.2.1 Substrate chain

Biomass suitable to be fermented is named 'substrate' or 'feedstock' (Deublin & Steinhauser, 2011). One of the fundamental issues regarding substrate is the decision on whether the organic waste is collected separately or whether mechanical sorting of the mixed waste is applied as part of the treatment process (Monnet, 2003). This is because the characteristics of incoming waste materials are highly dependent on the collection system (Hartmann, 2002). Source segregation of MSW generally provides biowaste of higher quality (purity) i.e. smaller quantities of non-degradable contaminants like glass, plastic and other materials. Mechanically sorted biowaste on the other hand is more contaminated which leads to persistent problems like clogging of pumps/pipes, lower biogas yield and lower acceptability of the resulting product. Monnet (2003) states that the desired 'cleanliness' of the waste stream should be defined in relation to the purpose of the AD plants. If the plant is intended to maximize the output of methane, mixed collection is suitable. If the purpose is to produce high quality residue, then the purity of the waste is very important. The composition of the municipal biowaste changes during the year due to seasonal variations and differences in regional practices (Li, Park & Zhu, 2011). This can for example include fasting seasons or certain festivals during which a specific kind of food or flower decoration is used, resulting in an increase of the respective waste.

Based on the characteristics of the incoming waste, the effect they exert on the digestion process and the selected AD technology itself, there are a variety of pre-treatment processes to be chosen from. The following list describes some of the reasons why pre-treatment of substrates is needed, i.e. why waste should be prepared prior to being fermented in the biogas plant and how it can be done (Deublin & Steinhauser, 2011):

- Non-degradable impurities and/or harmful materials like metals can cause disturbances in the liquid flow and possibly remain as noxious matter in the residue.
  → Removal through manual or magnetic separation

- Large lumps of substances or high amount of fibrous materials (e.g. green cuttings and straw) lead to process disturbances in the digester (blocking of pumps or formation of a gas-impermeable scum).
  → Comminution in a rotating drum, shredder or screw mills. Additionally, size reduction of substrate particles and the resulting increase in the specific surface available to the microorganisms improves the biological process. Hence comminution also leads to a higher gas production and a more rapid digestion.

- Too high or too low TS concentration in relation to the selected AD technology (wet or dry fermentation, see 5.3.1) can lead to diverse problems (clogging of pipes, mixing problems, unnecessarily high energy consumption to heat up digester content etc.)
  → Dilution with water (if TS is too high for chosen technology) or solid/liquid separation (if TS is too low for selected AD technology).

- Legal restriction which demand the sanitation of substrate so that the residue is harmless from an epidemic and phytohygienic point of view.
  → Thermal and chemical hygenization before or after the treatment in the biogas digester.

5.2.2 Biological reaction chain

Anaerobic digestion (AD), also referred to as biomethanization, is the biochemical decomposition of complex organic material by various bacterial activities in the absence of oxygen. The two main products of AD are the energy-rich biogas, and a mixture of bacterial biomass and inert organics, often referred to as digestate. Digesters or reactors are physical structures that facilitate anaerobic digestion by providing an anaerobic environment for the bacteria responsible for digestion (Mata-Alvarez, 2003).

Anaerobic digestion occurs in a four-step process, presented in Figure 18 below (Mata-Alvarez, 2003; Rapport et al., 2008).

Hydrolysis

The first step involves the extracellular enzyme-mediated transformation of large protein macromolecules, fats and carbohydrate polymers (such as cellulose and starch) into basic structural building blocks such as amino-acids, long-chain fatty acids, monosaccharides and related compounds which are suitable for bacterial use as a source of energy and cell tissue.

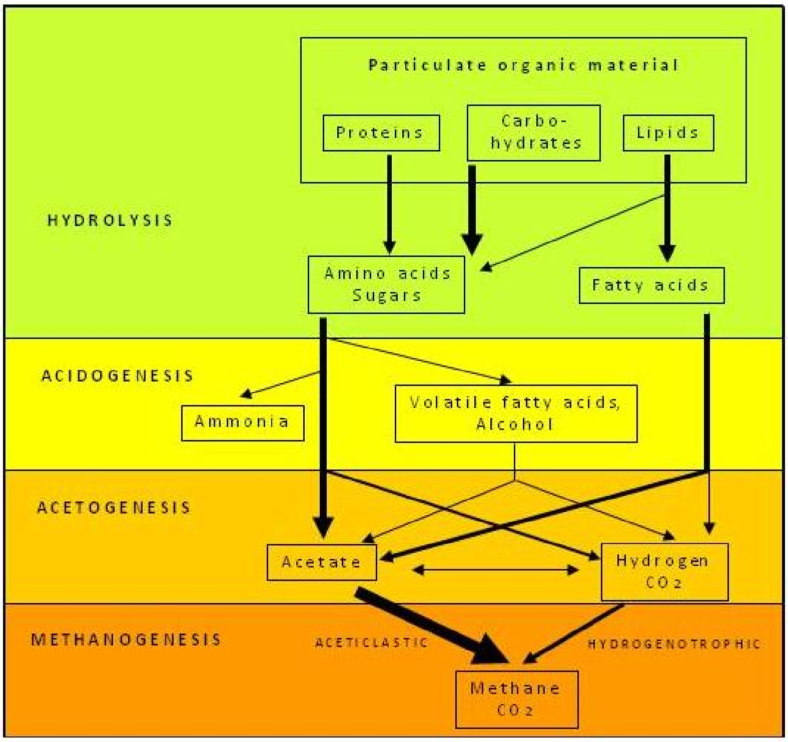


Figure 18: Schematic biodegradation steps of complex organic matter (adapted from Mata-Alvarez, 2003)

1. Acidogenesis

The fermentative bacteria degrade the soluble organic monomers of sugars and amino acids to form three-, four- and five-carbon volatile fatty acids (lactic, butyric, propionic and valeric acid), acetate, hydrogen and carbon dioxide. Ammonia is also produced through degradation of amino acids.

2. Acetogenesis

Both long chain fatty acids and volatile fatty acids are consumed by bacteria, generating acetate, carbon dioxide and hydrogen.

3. Methanogenesis

Finally, methanogenic organisms consume the acetate, hydrogen and some of the carbon dioxide to produce methane. The bacteria responsible for this conversion are strict anaerobes called methanogens.

Methane formation from biomass follows in general the following equation (Deublein&Steinhauser, 2011)

$$C_cH_hO_oN_nS_s + yH_2O \rightarrow xCH_4 + nNH_3 + sH_2S + (c-x)CO_2$$

Where $x = 1/8(4c + h - 2o - 3n - 2s)$

$y = 1/4(4c - h - 2o + 3n + 2s)$

The products include, for example, the following:

Carbohydrates: $C_6H_{12}0_6 \rightarrow 3CH_4 + 30_2$

Fats: $C_{12}H_{24}0_6 + 3H_2O \rightarrow 4.5CO_2 + 7.5CH_4$

Proteins: $C_{13}H_{25}0_7N_3S + 6H_2O \rightarrow 6.5CO_2 + 6.5CH_4 + 3NH_3 + H_2S$

5.2.3 AD product chain

The two main products of the AD process are biogas and digestate which are described below.

- **Biogas**

Biogas consists mainly of methane (CH_4) and carbon dioxide (CO_2), but also contains several impurities (Table 8). Biogas with methane content higher than 45% is flammable (Deublin & Steinhauser, 2011).It can be used in different applications depending on the cost, economy, safety, geographical location and availability (Gebren & Oelofse, 2009). The specific properties of biogas from biowaste are presented in Table 9.

Table 8: Typical composition of biogas from biowaste (Cecchi et al., 2003)

Components	Symbol	Concentration (Vol-%)
Methane	CH_4	55 - 60
Carbon dioxide	CO_2	35 - 40
Water	H_2O	2 (20°C) - 7 (40°C)
Hydrogen sulfide	H_2S	20 - 20'000 ppm (2%)
Nitrogen	N_2	< 2
Oxygen	O_2	< 2
Hydrogen	H_2	< 1

It is important to keep methane losses during the complete anaerobic digestion low for both economical as well as environmental reasons since methane is a greenhouse gas 21 times stronger than CO_2 (Persson, Jönsson & Wellinger, 2006). Uncontrolled 'methane slips' can result in counterproductive environmental effects of AD projects.

Table 9: Specific properties of biogas from biowaste

Composition	55 - 75% methane (CH_4) 30 - 45% carbon dioxide (CO_2) Traces of other gases	Source
Energy content	6.0 - 6.5 kWh/m^3	Deublein & Steinhauser, 2011
Fuel equivalent	0.6 - 0.65 l oil/m^3 biogas	Persson, Jönsson & Wellinger, 2006
Lower heating value	23 MJ/Nm^3; 6.5 kWh/Nm^3; 20.2 MJ/kg	"
Density	1.2 kg/Nm^3	"
Higher Wobbe Index	27 MJ/Nm^3	"
Explosion limits	6 - 12% biogas in air	Deublein & Steinhauser, 2011
Ignition temperature	650 - 750°C (with above mentioned CH_4 content)	"
Critical pressure	75 - 89 bar	"
Critical temperature	- 82.5°C	"
Normal density	1.2 kg/m^3	"
Smell	Bad eggs if not desulfurized / hardly noticeable if desulfurized	"
Molar Mass	16.043 g/mol	"

As can be seen in Table 9, the critical temperature of methane is around -82.5°C, i.e. even with a very high pressure it is not possible to liquefy methane at higher temperature. As a consequence, biogas cannot be stored over long periods at reasonable costs which makes this probably the most important bottleneck of biogas utilization (Mata-Alvarez, 2003). On a larger scale, biogas can be converted into electricity, which requires gas cleaning and gas storage capacity of about half a day to store the night production.

There are four basic ways of biogas utilization (Persson, Jönsson & Wellinger, 2006):

- Production of heat and steam
- Electricity production/co-generation
- Vehicle fuel
- Production of chemicals

The most common use from small-scale plants in developing countries is for cooking and lighting (production of heat). Conventional gas burners and gas lamps can easily be adjusted to biogas by changing the air to gas ratio.

Gebren & Oelofse (2009), with their predominant focus on developing countries, list three options for small-scale biogas utilization:

- Direct end-use
- Electricity generation
- Indirect end-use

They state that the most cost-efficient process for biogas utilization is direct use for cooking/heating, light or refrigeration rather than converting it to electricity because the change of biogas to electricity is accompanied by a significant loss in energy potential. Furthermore this conversion complicates the process which in the developing country context might be a crucial aspect. Direct end-use requires an end user within 2-3 km from the biogas generation site, preferably with a continuous demand and also preferably with a process that can use ‘dirty’, low-heating value gas.

There are three major reasons for gas cleaning (Persson, Jönsson & Wellinger, 2006):

- Fulfilling the requirements of gas appliances (gas engines, boilers, fuel cells, vehicles etc.)
- Increase the heating value of the gas
- Standardisation of biogas

As shown in Table 10, the gas quality requirements depend strongly on the utilization.

Table 10: Requirements to remove gaseous components (Persson, Jönsson & Wellinger,2006)

Application	H_2S	CO_2	H_2O
Cooking (kitchen stove)	yes	no	no*
Gas heater (boiler)	< 1000 ppm	no	no*
Stationary engine (CHP)	< 1000 ppm	no	no condensation
Vehicle fuel	yes	recommended	yes
Natural gas grid	yes	yes	yes

Desulphurisation is performed to avoid toxic H_2S concentrations; the maximal workplace concentration is 5 ppm. When biogas is burned, SO_2/SO_3 is emitted which is even more poisonous than H_2S. Furthermore, hydrogen sulfide (H_2S) has to be removed in order to avoid corrosion in pipework, compressors, gas storage tanks and engines. Hydrogen sulphide is extremely reactive with most metals. The reactivity is enhanced by concentration and pressure, the presence of water and elevated temperatures (Wellinger & Lindberg, 1999). H_2S can be removed from biogas by different chemical, physical and biological processes (Deublin & Steinhauser, 2011). The most common commercial methods for hydrogen sulphide removal are:

- air/oxygen dosing to digester biogas
- iron chloride dosing to digester slurry
- iron sponge
- iron oxide pellets
- activated carbon
- water scrubbing
- NaOH scrubbing
- biological removal on a filter bed
- air stripping and recovery

Detailed description of the different H_2S-removal procedures and a decision-making aid for which removal technology to apply can be found in Deublin & Steinhauser (2011, pp.442 - 451)

Besides lowering the density of the biogas, water (vapor) in the gas does not negatively affect or inhibit burning of biogas (*thus Table 10 does not indicate a necessity for its removal). However, because of potential accumulation of condensate in the gas line that can cause blocking of the gas pipe, water has to be removed by installation of a condense water trap. Another reason justifying H_2O removal from biogas is to avoid the formation of a corrosive acidic solution when hydrogen sulphide is dissolved. In addition, it is recommended to achieve low dew points when biogas is stored under elevated pressures in order to avoid condensation and freezing (Wellinger & Lindberg, 1999).

Removal of CO_2 is required if the biogas needs to be upgraded to natural gas standards or vehicle fuel use. It dilutes the energy content of the biogas but has no significant environmental impact (Wellinger & Lindberg, 1999).

- **Digestate**

As stated in 5.2.2, the use of biomass in AD also results in the production of a residual organic matrix named digestate that can be used in agriculture as nutrient fertilizers and/or organic amendment (Tambone et al., 2009). According to the nature of the treated waste and the AD technology used, the digestate can either be in a liquid or in a solid state. A solid/liquid separation process (centrifugation, pressing, drying) can be applied to produce different by-products with different uses (Teglia, Tremier & Martel, 2011). It is usually applied when part of the digestate has to be transported over a long distance (i.e. more than 10-15km) in order to reduce the volume (Wellinger & Lindberg, 1999).
Digestates can be valorized and used through spreading on agricultural lands, but several particular characteristics of digestates can reduce their potential for valorization. If digestate still contains complex organic elements such as ligno-cellulosic compounds, the digestate is not fully stabilized and can still present a residual biodegradability. As total nitrogen is conserved during AD, digestates are still rich in nitrogen. The nitrogen speciation is of particular interest as it can bring additional managerial issues. During digestion, a large part of nitrogen is converted into ammonium which can lead to potentially phyto-toxic digestates. Digestates can also be odorous, too wet or too concentrated in phyto-toxic volatile fatty acids when the reactor was not well designed, which prevents direct land application (Teglia, Tremier & Martel, 2011). Thus, AD residues may have to undergo an appropriate post-treatment step in order to ensure characteristics suitable for an agricultural use, i.e. efficiency and safety. Typical sequence of post-treatment steps for the digestates involves mechanical dewatering, aerobic maturation and water treatment (Vandevivere, De Baere & Verstraete, 2003). Aerobic maturation (composting) can be an adequate post-treatment for digestates when sufficient biodegradable organics are remaining. It stabilizes the residual organic matter, reduces phyto-toxicity and improves humic potential of digestates. If the material after biological treatment contains mainly recalcitrant or humus-like matter, it is not able to sustain microbial activity, and thus is considered stable. Stability prevents nutrients from being tied up in rapid microbial growth, allowing them to be available for plant needs (Trzcinski & Stuckey, 2011).

Teglia, Tremier & Martel (2011) define the required digestate quality for agricultural use by:
1. <u>Organic amendment properties:</u> Soil amendment is defined as material added to soil that will improve its physical properties (e.g. water retention, permeability, water infiltration, aeration/structure).
2. <u>Fertilizing effect:</u> fertilizers promote plant nutrition due to the provision of macronutrients (nitrogen, phosphorus and potassium). The major goal of fertilizer is to improve soil fertility and production yield of crop cultivation.
3. <u>Innocuousness:</u> The safe use of organic wastes on land depends on several factors including its potential impacts on general environment (soil, water, resources, air) and possible impacts on animal and human health (infections for digestate handlers and users, odor issues).

Both organic amendment properties of the digestate and potential impacts of it need to be investigated by field application of the digestate in soil to evaluate its effect on the soil nutrient status (nutrients properties) and humic substance balance (amendment properties) (Tambone et al., 2009). Digestate quality is not only related to the presence of organic and inorganic elements, but also to the absence of phytotoxicity and weed seeds (Trzcinski & Stuckey, 2011). Biotests are recommended to estimate the ecotoxicity of organic products before their use on land. These ecotoxic tests can consist of an estimation of growth inhibition for different living organisms such as bacteria or algae which are quite sensitive bio-indicators (Teglia, Tremier & Martel, 2011).

Health risks for humans or animals also have to be estimated before agricultural use of organic waste. The presence of faecal coliforms is often used as an indicator of the overall sanitary quality of soil and water environments as they generally occur at higher frequencies than the pathogens and are simpler and safer to detect. *Escherichia coli* is reported to be the most representative bacterium in the group of faecal coliforms but faecal streptococci are commonly considered as the best indicators of faecal pollution. *Staphylococcus aureus* is one of the main causes of collective infections of food and can also induce cutaneous infections hazardous for compost handlers and farmers. Among pathogens, *Salmonella* are the most studied and most frequently found so they have been proposed as indicator of pathogens behavious in sludge and composts. Helminth eggs are also currently quantified as they present a high resistance to environmental factors. Hygienization of waste after biological treatment will be assured by the reduction of several bacteria or pathogens in the end-product (Teglia, Tremier & Martel, 2011).

5.2.4 Design considerations (operational parameters)

Several factors need to be considered in the design of a digester suitable for biodegradation and stabilization of MSW, such as the type of waste, the rate of waste generation and local environmental conditions like ambient temperature (Igoni et al., 2007).
The rate at which the microorganisms grow is of paramount importance for the AD process (Verma, 2002). The operating parameters of the digester are hence to be controlled so as to enhance the microbial activity and thus increase the AD efficiency of the systems (Monnet, 2003). The most important parameters are described below. Concerning reactor operation, most commonly used indicators are Organic Loading Rate (OLR) and Solid Retention Time (SRT), together with classical monitoring parameters such as pH, Volatile Fatty Acids (VFA) or gas production (Buffiere et al., 2006).

- **Waste characteristics**

It is important to characterize incoming waste materials because the better the understanding of the substrate, the better the AD technology and operational parameters can be selected. A rough and relatively easy characterization of waste is the analysis of Total Solids (TS) and Volatile Solids (VS). TS means the dry matter content and presents a raw estimation of all organic and inorganic matter content in the sample, while the remainder is the water content.
VS is an approximation for the organic fraction of the dry matter. TS and VS are important as they determine the most common indicator of digester performance, which is the amount of methane produced per mass unit of solid or volatile solid matter (Buffiere et al., 2006).

Table 11 presents some values found in literature in terms of TS and VS contents of different organic wastes.

Table 11: TS and VS contents in biowaste

Substrate	TS [%]	VS [%]	Source
Biowaste	60-75	50-70	Eder & Schulz (2006)
Kitchen waste	9-37	50-70	"
Market waste	28-45	50-80	"
Spent fruits	25-45	90-95	Deublein & Steinhauser (2011)
Vegetable wastes	5-20	76-90	"
Market wastes	8-20	75-90	"
Leftover (canteen)	9-37	75-98	"
Biowaste (household)	40-75	30-70	"
Overstored food	14-18	81-97	"

Chemical Oxygen Demand (COD), which stands for the oxygen equivalent of the organic matter that can be oxidized, is another very useful and often applied parameter to measure the content of organic, biodegradable matter in the waste (Lohri, 2009).

Organic materials are increasingly difficult to degrade according to the sequence: sugar – protein – fat – hemicellulose – cellulose – lignin (Deublein & Steinhauser, 2011). Thus the biodegradability decreases with the increase of the ligno-cellulosic content in the waste; particularly high lignin-cellulose ratios are difficult to degrade.

- **Temperature**

There are two temperature optima for the involved AD bacteria; one at 30-40°C for mesophilic microorganisms (optimum temperature 37°C) and one at 45-60°C for thermophilic microorganisms (optimum temperature 55°C) (Mata-Alvarez, 2003). The operation in the mesophilic range is more stable, can tolerate greater changes in environmental parameters and requires a smaller energy expense; but entails a longer retention time. The inhibition of ammonium is reduced compared to thermophilic conditions due to the lower content of free ammonia. The thermophilic mode of operation results in about a 50% higher rate of degradation and, particularly with fat-containing materials, a better availability of the substrates to the enzymes exerted by the acidogens and thus higher biogas yield (Deublein & Steinhauser, 2011).

- **pH**

Most literature shows an optimum pH in the range of 6.5 – 7.5, which is considered best as the AD process is generally stable and biogas yield is maximised (Mata-Alvarez, 2003; Khalid et al., 2011). During digestion, the processes of hydrolysis and acidogenesis require different pH levels for optimal process control (pH 5.5 - 6.5) compared to methanogenesis (pH 6.5 - 8.2) (Khalid et al., 2011). Sufficient alkalinity up to a level of approximately 3'000 mg/L has to be available all the time for sufficient buffering to be maintained. Lime is commonly used to raise the pH of AD systems when there is a process imbalance, but excess lime can result in precipitation of calcium carbonate. Alternatively, sodium bicarbonate can be used for pH adjustment (Igoni et al., 2007).

- **C/N ratio**

The relationship between the amount of carbon and nitrogen in organic materials is represented by the C/N ratio. C/N ratio is an important parameter in estimating nutrient deficiency and ammonia inhibition (Hartmann, 2002). Optimum C/N ratios in anaerobic digesters are between 16 and 25 (Deublein& Steinhauser, 2011). A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens (which in general have a low yield and therefore a low nutrient requirement) and results in lower gas production. On the other hand, a lower C/N ratio causes ammonia accumulation and pH values exceeding 8.5, which can be toxic to methanogenic bacteria (Verma, 2002). However, methanogens also show ability to adapt to very high ammonia concentration if concentration is gradually increased. Optimum C/N ratios can be achieved by mixing materials of high and low C/N ratios, such as organic solid waste mixed with sewage or animal manure.

- **Retention time**

The required hydraulic retention time (HRT) for completion of AD reactions varies with differing technologies, process temperature and waste composition. HRT for wastes treated in mesophilic digester range from 10 to 40 days. Lower retention times down to a few days are required in digesters operated in the thermophilic range (Verma, 2002). A distinction is made between hydraulic retention time (HRT) and solids retention time (SRT), but for digestion of solid waste, HRT and SRT are in general equal (Zeeman, 2011).

- **Organic Loading Rate (OLR)**

OLR is a measure of the biological conversion capacity of the AD system. It stands for the substrate quantity introduced into the reactor volume in a given time (OLR = Q*S/V, where OLR is expressed in kg substrate/m^3 reactor day, Q stands for substrate flow rate in m^3/day, S for substrate concentration in the inflow in kg/m^3 and V stands for reactor volume in m^3, Mata-Alvarez, 2003). It is a particularly important control parameter in continuous systems, as overloading leads to a significant rise in volatile fatty acids which can result in acidification and system failure (Verma, 2002). Many studies on the anaerobic treatment of biowaste found organic loading rates in the range 4–8 kg VS m^3/ day, which resulted in VS removals in the range of 50–70% (Vandevivere, De Baere & Verstraete, 2003).

- **Mixing**

The purpose of mixing is to blend the fresh material with digestate containing microbes. It avoids temperature gradients within the digester and also prevents scum formation. Scum and foam is a result of filamentous microorganisms in the digester. Low concentrations of substrate in AD plants lead to an advantage in growth of filamentous bacteria versus flocculating bacteria. Rising scum in digesters can result in blockage of the gas pipe or potentially lead to a foaming over the digester. Thickened scum can prevent gas release (Deublein & Steinhauser, 2011). The kind of mixing equipment and amount of mixing varies according to reactor type and TS content in the digester (Verma, 2002).

- **Biogas yield**

Khalid et al. (2011) write that biogas yield is affected by many factors including type and composition of substrate, microbial composition, temperature, moisture and bioreactor design. In general, food waste gives the highest biogas yield, which will decrease with increasing amounts of yard waste and low quality paper in the collected biowaste.

If the exact chemical composition of the substrate is known or can be analyzed, the Buswell formula can be applied. It is a net formula for biogas production based upon the stoichiometry of the degradation (input organic matter) reaction:

$$C_a H_b O_c N_d + \left(\frac{4a - b - 2c + 3d}{4}\right) H_2O \rightarrow \left(\frac{4a + b - 2c - 3d}{8}\right) CH_4 + \left(\frac{4a - b + 2c + 3d}{8}\right) CO_2 + dNH_3$$

The most common indicator of digester performance is the BMP (biological methane potential), which gives the maximum methane amount of methane gas that can be produced per mass unit of solid or volatile solid matter (Buffiere et al., 2006). The methane potential of various types of wastes is generally expressed with this simple criterion (e.g. Gunaseelan, 2004). This description is often sufficient to compare the digestibility of waste having the same nature or to compare different reactor designs with a given waste. Another way of measuring digester performance is gram CH_4-COD per gram COD input. The hydrolysis rate and SRT determine the amount of gas produced in the reactor, considering hydrolysis as the rate limiting step.

Table 12: Biogas yield recorded from anaerobic digestion of the solid organic waste (Khalid et al., 2011)

Substrate	Methane yield (L/kg VS)	References
Fruit and vegetable waste & abattoir wastewater	850	Forster-Carneiro et al (2007)
Palm oil mill waste	610	Fang et al (2011)
Municipal solid waste	530	Forster-Carneiro et al (2007)
Jatropha oil seed cake	422	Chandra et al (2011)
Fruit and vegetable wastes	420	Bouallagui et al (2005)
Food waste	396	Zhang et al (2011)
Municipal solid waste	360	Vogt et al (2002)
Rice straw	350	Lei et al (2010)
Household waste	350	Ferrer et al (2011)
Swine manure and winery wastewater	348	Riano et al (2011)
Swine manure	337	Ahn et al (2009)
Maize silage and straw	312	Mumme et al (2010)
Food waste leachate	294	Behera et al (2009)
Municipal solid waste	200	Walker et al (2009)
Lignin-rich organic waste	200	Jayasinghe et al (2011)

- **Inhibition**

When planning and operating a biogas plant, it needs to be kept in mind that some compounds inhibit the anaerobic process and can even be toxic at higher concentrations. Generally speaking, the inhibition depends on the concentration of the inhibitors, the composition of the substrate and the adaptation of the bacteria to the inhibitor. Deublein & Steinhauser (2011) list the following inhibitors: Oxygen, hydrogen sulfide (H_2S), organic acids, free ammonia, heavy metals, tannins/saponins/mimosine and others such as disinfectants (from hospitals or industry), herbicides, insecticides (from agriculture, market, gardens, households) and antibiotics.

As ammonia nitrogen is often referred to as one of the common and relevant inhibiting substances of AD, its effect is briefly explained: The un-dissociated ammonia form, unlike the ammonium ion, is able to diffuse through the cell membrane, which has been reported to inhibit cell functioning by disrupting the proton and potassium balance inside the cell, therefore making the free ammonia as the main inhibitory form for methanogenesis (Kayhanian, 1999). This inhibition will cause accumulation of intermediate digestion products like volatile fatty acids (VFA) which can result in acidification.

5.3 AD technologies for biowaste

Overall, the anaerobic treatment technology of biowaste is considered to be mature in many aspects (Mata-Alvarez, Mace & Llabres, 2000). The digestion efficiency and stability can vary significantly depending upon the type of digester used and the parameters of its operation. Digesters range in complexity from simple cylindrical cans with no moving parts to fully automated industrial facilities. The multitude of digester varieties are designed to optimize the process for specific climatic conditions, types of waste and other considerations (Ostrem, 2004). Vandevivere, De Baere & Verstraete (2003) observe a general acceptance that a wide variety of digester types are functioning at full-scale in a reliable way. It is not possible to single out specific designs as overall and optimally most suitable under all circumstances. Many variables have to be taken into consideration and a final evaluation for the specific site is required.

Various classification schemes have been used by different authors to categorize AD technology systems for MSW. Vandevivere, De Baere & Verstraete (2003) write that comparison of research data and drawing of conclusions is difficult because the great diversity of reactor designs is matched by a large variability of waste composition and choice of operational parameters. The following section illustrates the wide and somewhat controversial variety of classifications used in literature. A simplified classification model is proposed afterwards.

Vandevivere, De Baere & Verstraete (2003) and Khalid et al. (2011) distinguish between three major groups of bioreactors commonly in use:

1. Batch reactors: One stage and two stage
2. One-stage continuously fed system: Low solids (wet) and high solids (dry)
3. Two-stage continuously fed system: Dry-wet and wet-wet

Li, Park & Zhu (2011) classify AD processes according to critical operating parameters and reactor design:

1. Continuity (batch vs. continuous)
2. Operating temperature (psychrophilic, mesophilic, thermophilic)
3. Reactor design (plug-flow, complete-mix, covered lagoon)
4. Solid content (wet vs. dry).

According to Nichols (2004), the different anaerobic digestion processes on the market for source separated organic waste or MSW have the following primary characteristics:

1. Number of stages: Single-stage and two-stage
2. Feed total solids (TS) content: Wet process (<20% TS) and Dry process (>20% TS)
3. Operating temperature: Mesophilic process (34-37°C) and thermophilic process (55-60°C)
4. Agitation: Gas Injection, internal mechanical components (agitator) or re-pumping/recirculation
5. Reactor Type: Vertical positioning and horizontal positioning
6. Process Flow: Continuous process flow (CSTR) and plug flow process (PFR)

RISE-T (1998) uses the following four categories:

1. Wet or Dry
2. Batch or Continuous
3. Single step or multi-step
4. Co-digestion with animal manure or digestion of MSW alone

The classification categories described by Ostrem (2004) are:

1. Capacity
2. Vertical or horizontal orientation
3. Batch or continuous flow
4. Total solids content
5. Number of stages
6. Mixing
7. Pre-treatment

Four main categories have been suggested for classification by Zeeman (2011): CSTR, PFR, Batch and Fed-Batch systems (continuous with respect to filling, discontinuous with respect to emptying).

The six characteristics considered to be of highest relevance are briefly described below.

- **Operating temperature: Mesophilic / Thermophilic**

According to Hartmann & Ahring (2006), AD was traditionally applied in the mesophilic temperature range of ambient temperature and up to 37°C. It was believed that thermophilic processes were less stable and led more rapidly to process failure. Throughout the recent 15 years, however, more and more thermophilic biogas plants have been established in Europe and nowadays for example in Denmark, most of the centralized biogas plants are operated under thermophilic conditions. Thermophilic operation offers the advantage of a higher reaction rate causing a more profitable process with a lower retention time. Thermophilic operation also leads to a better hygienisation of the waste material compared to mesophilic treatment (Hartmann & Ahring, 2006), but the mesophilic process is considered to be more stable (see 5.2.4)

- **Continuity of feeding: Batch / Continuous**

Batch reactors are filled with a feedstock and left for a period that can be considered to be the retention time, after which they are emptied (Khalid et al., 2011). Vandevivere, De Baere & Verstraete (2003) state that batch systems are in general the lowest-tech of all systems and also the cheapest. They list three types of batch systems: Single stage batch systems, sequential batch systems and UASB (Upflow Anaerobic Sludge Blanket for wastewater) batch reactors. The major drawbacks of the first two are a large footprint and a lower biogas yield due to the impairment of the percolation process when pipes, channeling and nozzles get clogged . Due to their simple design and process control, robustness towards coarse and heavy contaminants and lower investment costs make batch systems particularly attractive for application in developing countries (Burri & Martius, 2011). On the other hand, batch reactors have some limitations such as high fluctuations in gas production as well as gas quality, biogas losses, risk of explosion during emptying bioreactors and restricted bioreactor heights (Vandevivere, De Baere & Verstraete, 2003).
Continuous stands for a reactor that is fed continuously with substrate while degraded material is continuously being removed from the reactor (RISE-AT, 1998)

- **Total Solids content: Dry / Wet**

Different definitions can be found in literature in terms of which TS content is required for classification as dry system. According to Ward et al. (2008) wet bioreactors have a TS of 16% or less, while dry bioreactors contain 22-40% TS, with the intermediate rating termed 'semi-dry'. According to Karagiannidis & Perkoulidis (2009), dry systems contain 30-40% dry matter and wet systems contain 10-25% dry matter. Li, Park & Zhu (2011) state that solid-state AD generally occurs at solid concentrations higher than 15%. In contrast, liquid AD handles feedstock with solid concentrations between 0.5% and 15%. Hartmann & Ahring (2006) write that the process is termed low-solids (wet) with TS < 20% and high-solids (dry) process with TS > 20%.

The challenges of dry system include handling, mixing and pumping the high-solids streams rather than maintaining the biochemical reactions (Rapport et al., 2008). According to Li, Park & Zhu (2011), dry systems have been claimed to be advantageous over liquid AD for a number of reasons including smaller reactor volume, lower energy requirements for heating, minimal material handling, and lower total parasitic energy loss. Due to its low moisture content, the digestate of dry AD can be used as fertilizer or pelletized fuel, which is easier to handle than the effluent of liquid AD. Despite the numerous advantages of dry AD technology and progress in system designs, numerous aspects need to be improved for further commercialization of the technology. The retention time of dry AD has been documented to be up to three times longer than liquid AD due to the slower mass transportation in dry AD compared to that of liquid AD (Li, Park & Zhu, 2011).

- **Substrate: Single feedstock / Co-digestion**

Co-digestion, also termed co-fermentation, is a waste treatment method in which different wastes are mixed and treated together. It is preferably used for improving yields of AD of solid organic wastes due to its numeral benefits including dilution of toxic compounds, improved balance of nutrients (C/N ratio) and better biogas yields as a result of increased load of biodegradable organic matter (Khalid et al., 2011). As an example of advised co-digestion: If substrate has a low buffer capacity, it is recommended to add manure (Zeeman, 2011).

- **Number of stages: One stage / Multi stage**

The rationale of two- and multi-stage systems is that the overall conversion process of biowaste to biogas is mediated by a sequence of biochemical reactions that do not necessarily share the same optimal environmental conditions. Optimizing these reactions separately in different stages or reactors may lead to a larger overall reaction rate and biogas yield. Typically, two stages are used where the firsts one harbors the liquefaction-acidification reactions, with a rate limited by the hydrolysis of cellulose, and the second one harbors the acetogenesis and methanogenesis, with a rate limited by the slow microbial growth rate (Mata-Alvarez, 2003).

Single-phase treatment is generally the more predominant AD treatment applied in full-scale for biowaste (Hartmann, 2002). According to Mata-Alvarez (2003), about 90% of the full-scale plants currently in use in Europe for AD of biowaste rely on one-stage systems and these are approximately evenly split between 'wet' and 'dry' operating conditions. Although multi-stage systems (only 10% of the current overall treatment capacity) theoretically enable to control and investigate the intermediate steps of the digestion process (Vandevivere, De Baere & Verstraete, 2003), it is disputed among researchers if this leads to better performance. Biological performance of one-stage systems is, for most organic wastes, as high as or even better than that of two-stage systems (Zeeman, 2011), provided the reactor is well designed and operating conditions carefully chosen (Mata-Alvarez, 2003). Industrialists often prefer one-stage systems because simpler design suffers less frequent technical failures and has smaller investment costs. A first stage with OLR buffering is beneficial and useful only for treatment of cellulose-poor substrates for which methanogenesis rather than hydrolysis-acidification is the rate limiting step (Vandevivere, De Baere & Verstraete, 2003).
Rapport et al. (2008) state that single stage systems are simple, easy to design, build and operate and generally less expensive. According to Nichols (2004), single stage is mainly for comparatively small, decentralized waste management units, while multistage digestion is suitable for plants with capacity of more than 50'000 tons/year.

- **Scale: Decentralized (small-scale) / Centralized (large-scale)**

RISE-AT (1998) distinguish between small scale systems with a capacity of less than 2'000 tons/year (5.5t/day) and large scale systems with a capacity of more than 2'000 tons/year. Measurements of scale often refer to the following interrelated aspects:

- Input of biomass, tons per year or per day
- Size of the tank, volume in cubic meters
- Energy produced, power in MW or kW

A simple visual classification model is proposed in order to enable a quick understanding of the most important characteristics of an AD technology for biowaste.

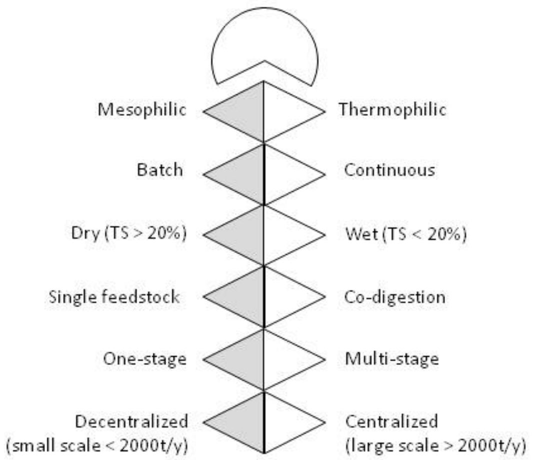


Figure 19: Template of visual classification for AD technologies

Figure 19 presents the template of the classification model. The chosen classification parameters are (from top to bottom): Temperature, feeding continuity, solids content, substrate, number of stages and scale. The characteristics situated on the left side are generally considered to require less technological advanced equipment, materials and financial resources, thus stand for rather low-tech technologies (grey area). In contrast, the characteristics positioned on the right side of the circle represent rather high-tech options which demand more efforts, logistics, energy and resources. However, this does not imply that technological set-ups showing characteristics of the left (grey) side will necessarily be a better solution for developing countries. Local circumstances always need to be taken into consideration.

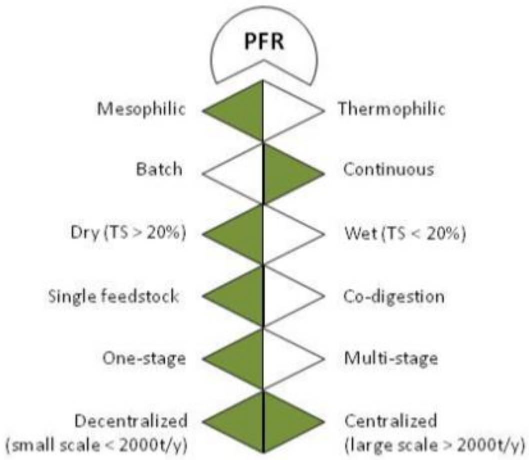


Figure 20 presents an illustration of the visual classification as applied on the example of the KOMPOGAS technology, a dry fermentation plug flow reactor (PFR, marked on top) operating under mesophilic conditions (technology is described later on). As the technology has been implemented on small-scale (1'000 t/y) as well as on large-scale (up to 110'000 t/y) the area is colored in green on both decentralized and centralized side.

Figure 20: Visual classification example KOMPOGAS technology

5.3.1 AD technologies of biowaste in high-income countries

As mentioned before (5.1), anaerobic digestion technology development has been underway in Europe for biowaste for over 30 years, driven by the issue of dwindling landfill space (Nichols, 2004). According to Monnet (2003), European countries have come under pressure in recent times to explore AD market for two significant reasons: higher energy prices and increasingly stringent environmental regulations. By the end of 2006, there were 124 AD plants with capacity greater than 3'300 tons/y treating feedstock composed of at least 10% MSW. The combined capacity was 4.3 million tons/y, which is twice the number of plants and four times the capacity that existed in 2000 (De Baere 2000; De Baere, 2006).
The capacity of dry fermentation processes in Europe was estimated to be 54% of the total AD processes for biowaste in the year 2000 (De Baere, 2000). For treatment of MSW, experiences in Europe indicate that roughly 15'000 to 20'000 tons/year is the minimal quantity at which the AD of MSW becomes financially viable (Monnet, 2003). There is a recent trend to be observed toward larger digesters. This is in contrast to the years 1990 - 1995, when average digester size declined as developers were facing problems in scaling up what were previously lab- and pilot scale systems. As technologies advanced and experiences accumulated in managing larger systems, the average digester size increased from 1995 to 2004. The average size of the 52 plants installed in the period from 2001-05 was 47'300 t/y (Rapport et al., 2008). Despite the facts that AD of biowaste is well established in Europe and the increased use of AD in general, only an average of about 3% of biodegradable solid waste in Europe is treated anaerobically. Aerobic composting remains the primary means of OFMSW biological treatment in Europe, treating about 7% of household's organic waste (Rapport et al., 2008). The trend in biogas usage in most of the industrialized countries is towards pipeline quality methane or vehicle fuel whereas in the UK it is towards electricity generation due to new government incentives (Schwager, 2008). Although the U.S. does currently not have an operational full-scale plant of AD for MSW, many pilot projects have been conducted and lessons accumulated (Rapport et al., 2008).

- **<u>Europe</u>**

Table 13 presents a list from Rapport et al. (2008) which attempts to summarize the research reported in the literature for many of the existing and emerging systems, with special attention paid to the most commercially successful and innovative AD treatment technologies for source-separated organic waste and MSW.

Table 13: Summary of commercial large scale AD technologies (Rapport et al., 2008; based on data from Nichols, 2004 and company websites as of February 2008)

	No. of plants [1]		***Capacity [t/y]*** [2]		***Continuity of feeding***			***Temp. [°C]***		***TS-content***		***No. of stages***	
	< 10	*> 10*	*1'000-60'000 Small-medium*	*65'000-270'000 Large scale*	*CSTR*	*PFR*	*Batch*	*35*	*55*	*Wet <20%*	*Dry >20%*	*1*	*2*
AAT	8		3'000-55'000		x			x		x		x	
Arrow Bio	4			90'000-180'000	x			x		x			x
BTA*		23	1'000 -	150'000	x			x &	x	x		x &	x
Biocel*	1		35'000				x	x			x	x	
Biopercolat	1			100'000	x			x			x		x
Biostab		13	10'000 -	90'000	x				x	x		x	
DBA-Wabio	4		6'000-60'000		x			x		x		x	
DRANCO*		17	3'000 -	120'000		x			x		x	x	
Entec	2		40'000 -	150'000	x			x		x		x	
Haase	4		50'000 -	200'000	x			x &	x	x			x
KOMPOGAS*		38	1'000 -	110'000		x			x		x	x	
Linde-KCA/ BRV	8		15'000 -	150'000	x			x &	x	x		x &	x
Schwarting-Uhde	3		25'000 -	87'500	x				x	x			x
Valorga*		22	10'000 -	270'000		x		x &	x		x	x	
Waasa*		10	3'000 -	230'000	x			x &	x	x		x	

[1] Includes operational or planned plants that accept any of the following: MSW, kitchen waste, food waste, yard waste or green waste. Does not include food processing waste or wastewater. May include co-digestion with other organics such as biowaste or sewage sludge.
[2] Because metric tons are only slightly larger than short tons and the capacity range is approximate, no conversion was included.
* Briefly described underneath

Six different AD technologies are presented underneath. The selection is based on most successful, popular models and also aims at giving an idea of the range of technological diversity.

- <u>WAASA</u>

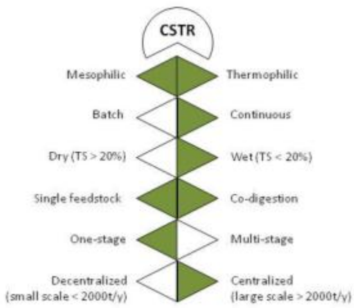


Figure 21: Characteristics of WAASA-technology

The WAASA process, developed 1998 by CITEC (Finland), was one of the original solid waste digesters. Initially designed as a wet, mesophilic and single-stage technology, the WAASA process is operated now at both thermophilic and mesophilic temperatures. The vertical reactor consists of a single vessel although it has been subdivided internally to create a pre-digestion chamber (Nichols, 2004).

- <u>DRANCO</u>

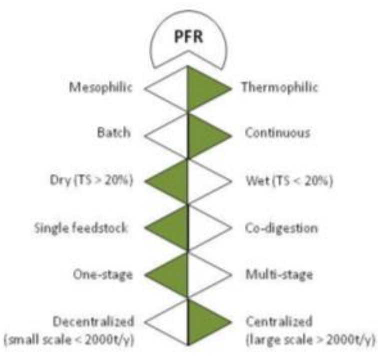


Figure 22: Characteristics of DRANCO technology

Organic Waste Systems (OWS) of Belgium developed the DRANCO process (dry anaerobic composting) for the anaerobic treatment of MSW and industrial organic waste. The first facility on industrial scale began operating in 1992. DRANCO features a thermophilic, single step anaerobic fermentation taking place in an enclosed vertical digester, followed by a short aerobic maturation phase. Characteristic for the DRANCO digestion is the "stationary" fermentation feeding the reactor once a day from the top of the reactor. Mixing is carried out by injection of biogas at the base of the reactor (Nichols, 2004).

- <u>KOMPOGAS</u>

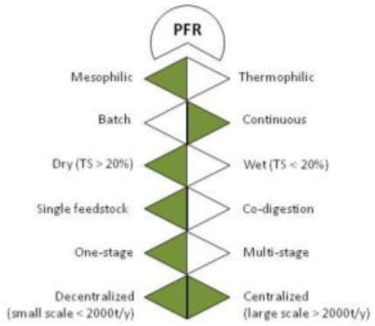


Figure 23: Characteristics of KOMPOGAS technology

The Swiss company KOMPOGAS was established at the end of the 1980s. Feedstock is loaded daily into cylindrical reactors; the plug-flow occurs horizontally, aided by slowly rotating and intermittently acting impellers inside the reactor. The system must be carefully monitored to maintain the TS content between 23-28% in the reactor so that flow can continue unimpeded and heavy particles remain in suspension (Nichols, 2004).

- <u>Valorga</u>

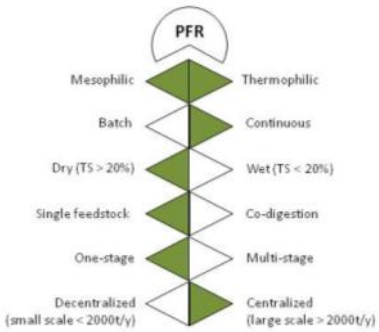


Figure 24: Characteristics of Valorga technology

Based in France, Valorga was founded in 1981 to develop MSW treatment technologies. Besides crushing, its trademark feature is the dry ballistic separation to remove the heavy fraction and other contaminants of the feedstock in the pretreatment step, before the waste is sent to the digesters. Digestion occurs within the mesophilic or thermophilic temperature range in a single reactor which is designed as a vertical cylindrical tank allowing "extraction by gravity“. The digestion reactor is designed as a vertical cylindrical tank allowing "extraction by gravity." Mixing of the mass is done with a high pressure biogas injection though a network of nozzles located at the reactor’s base (Nichols, 2004).

- <u>Biocel</u>

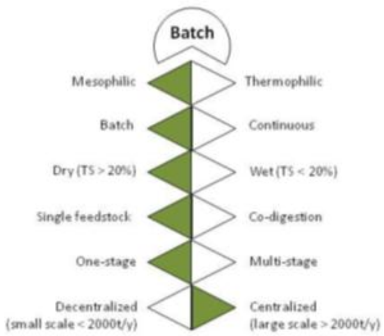


Figure 25: Characteristics of Biocel technology

The Biocel system was developed in the 1980s and 1990s in Holland at Wageningen University as part of the early research on high-solids digestion of MSW. Several units are subsequently filled. It may appear as nothing more than a landfill-in-a-box, but it achieves 50-100-fold higher biogas production rates compared to landfills. One reason is that the leachate is collected in chambers under the reactors, re-circulated and sprayed on the top surface of the fermenting wastes. Safety measures need to be closely observed during the opening and emptying of the batches, as explosive conditions can occur (Vandevivere, De Baere & Verstraete, 2003).

- <u>BTA</u>

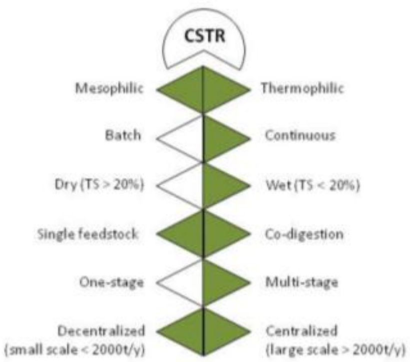


Figure 26: Characteristics of BTA technology

Developed in Germany and applied throughout Western Europe and in Canada and Japan, the BTA (Biologische Abfallverwertung GmbH & Co KG) system is one of the oldest and most successful in terms of number of existing operational digesters. Although small units are single-stage, the majority of the BTA digesters are large (>110,000 t/y) multi-stage, wet-wet units. In the multi-stage BTA digester, the pulped and density-fractionated MSW passes through a solid/liquid separation unit and leachate is passed directly to a methanogenesis reactor. Solid extract is mixed with process water and then pumped into a hydrolysis reactor. Hydrolysis leachate is transferred into the methanogenesis reactor. Dewatered digestate is either treated aerobically or disposed of (Rapport et al., 2008).

5.3.2 AD technologies for biowaste in developing countries

This section summarizes the literature found about AD technologies for biowaste that have been applied in developing countries with a special focus on Africa (RISE-AT, 1998; Müller, 2007; Gebren & Oelofse, 2009; Mshandete & Parawira, 2009; Parawira, 2009; Amigun & von Blottnitz, 2010). AD systems in rural areas and those predominately using toilet wastes are not specifically considered.

Some of the first biogas digesters were set up in Africa in the 1950s in South Africa and Kenya. In other countries such as Tanzania, biogas digesters were first introduced in 1975 and in some even more recently like South Sudan in 2001. The interest in biogas technology in Africa has been stimulated by the promotional efforts of various international organizations and foreign aid agencies (Parawira, 2009).
Amigun & von Blottnitz (2010) write that biogas technology has not been widely adopted by sub-Saharan households despite the recognized technical viability and acceptability of the technology; the multiple benefits recognized by users, governments and NGOs; and the estimates of large potential markets. Parawira (2009) confirms that biogas is overall not widespread in Africa and groups the reasons of constraints for biogas implementation in political, socio-cultural, financial, informational, institutional, technical and training. He lists some of the difficulties thwarting development of biogas technology in Africa:

- Inexperienced contractors /consultants, resulting in poor-quality plants and poor choice of materials
- Lack of reliable information on the potential benefits of the technology by financial institutions
- Absence of academic, bureaucratic, legislation and commercial infrastructure in the region/country
- Lack of knowledge on the system in practice, sometimes even in research institutes and universities
- Poor ownership responsibility by users
- Complete absence of pilot studies, and no full-scale experience
- No properly educated operators, lack of credibility and technical knowledge on maintenance/repair
- Uninformed or poorly informed authorities and policy makers
- Failure by government to support biogas technology through focused energy policy
- Research at universities frequently considered to be too academic in nature, even when it is quite applied.

Parawira (2009) further states that the main limitations to the adoption of large-scale biogas technology are both institutional and economic. Establishing a self-sustaining institutional system that can collect and process urban waste and effectively market the generated biogas fuel is a complex activity that calls for sophisticated organizational capability and initiative. Additional economic factors are cost of biomass material, biogas production costs, cost of corresponding fossil fuel and strategic benefit of substituting imported petroleum with domestic resources.
The three major types of digesters that have been used in developing countries are (Parawira, 2009): Chinese fixed dome digester, the Indian floating drum digester and more recent tube digesters. These three types and their respective advantages and disadvantages are explained underneath.

- **<u>Fixed dome digester</u>**

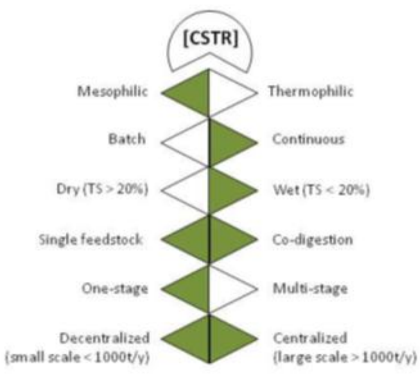


Figure 27: Characteristics of fixed dome technology

A fixed dome plant consists of a closed, dome-shaped digester (stone or brick masonry) with an immovable, rigid gasholder and a displacement pit, also named 'compensation tank'. The digester is completely buried underground to ensure uniform temperature distribution, to save space and to make use of soil support (Polprasert, 1996). The gas is stored in the upper part of the digester. When gas production begins, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low (ISAT/GTZ, 1999). A fixed dome digester can be considered as 'quasi-CSTR' because of the mixing through frequent feeding.

Advantages

- Relatively low construction costs
- Absence of moving parts and rusting steel parts
- Long life span (20 years) if well constructed
- The underground construction saves space and protects the digester from temperature changes.
- The construction provides opportunities for skilled local employment (ISAT/GTZ, 1999).

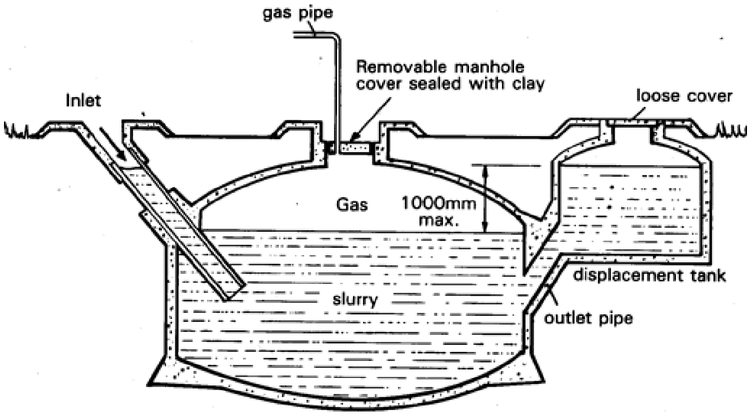


Figure 28: Schematic of fixed dome digester [13]

Disadvantages

- Frequent problems with gas-tightness of the brickwork gas holder (a small crack in the upper brickwork can cause heavy losses of biogas).
- Fixed-dome plants are, therefore, recommended only where construction can be supervised by experienced biogas technicians.
- The gas pressure fluctuates substantially depending on the volume of the stored gas.
- Even though the underground construction buffers temperature extremes, digester temperatures are generally low (ISAT/GTZ, 1999).

Some of the existing and successfully implemented models of fixed dome digesters are:

- Chinese fixed-dome plant: The archetype of all fixed dome plants. Several million have been constructed in China. The digester consists of a cylinder with round bottom and top.
- Deenbandhu: Designed in India as successor of the Janata-model. The improved design of Deenbandhu with a hemisphere digester was more crack-proof and consumed less building material than the Janata-model.
- CAMARTEC: Developed in the late 80s in Tanzania, this model has a simplified structure of a hemispherical dome shell based on a rigid foundation ring only and a calculated joint of fraction, the so-called weak / strong ring.
- GGC2047: Developed in the year 1990/91 (Nepali calendar: 2047), this design originates by its shape from a Chinese designed fixed dome digester dated back to 1980

- **Floating dome digester**

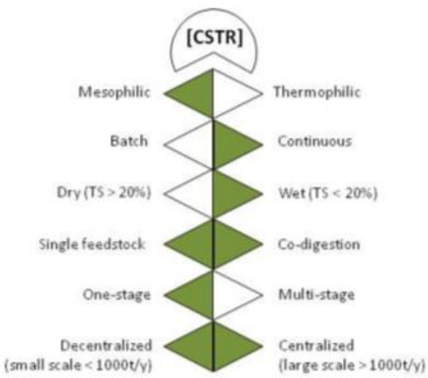


Figure 29: Characteristics of floating dome technology

Floating-drum plants consist of a (most of the time underground) digester and a moving gas-holder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own (to reduce methane slip). The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guiding frame (ISAT/GTZ, 1999). A floating dome digester can also be considered as ‘quasi-CSTR’ because of the mixing through frequent feeding.

Advantages

- Simple, easily understood operation - the volume of stored gas is directly visible
- The gas pressure is constant, determined by the weight of the gas holder
- The construction is relatively easy, construction mistakes do not lead to major problems in operation and gas yield (ISAT/GTZ, 1999)

Disadvantages
- High material costs of the steel drum,
- The susceptibility of steel parts to corrosion.
- Because of this, floating drum plants have a shorter life span than fixed-dome plants and regular maintenance costs for the painting of the drum (ISAT/GTZ, 1999).

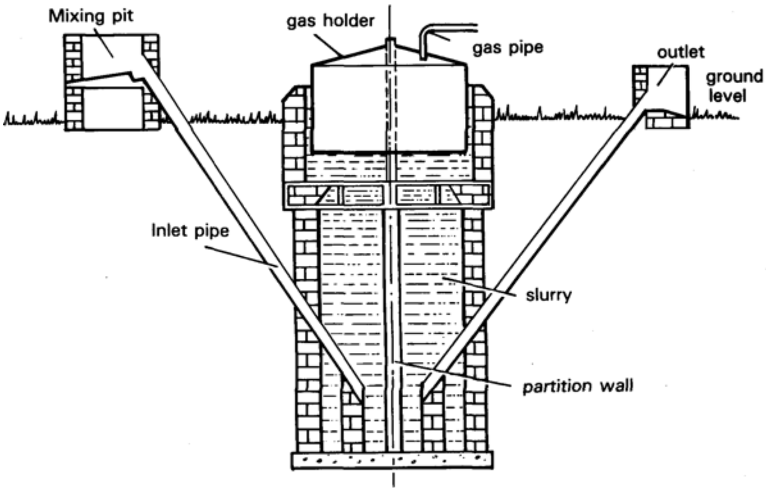


Figure 30: Schematic of floating dome biogas digester [13]

Some of the existing and successfully implemented models of floating-drum plants are:

KVIC model: Designed by the Khadi and Village Industries Commission (KVIC), this model consist of a cylindrical well and is the oldest and most widespread floating drum biogas plant from India.
ARTI: The Indian organization Appropriate Rural Technology Institute (ARTI) in 2003 developed a small-scale biogas system designed for household level use. The ARTI compact biogas system is made from two cut-down standard high-density polyethylene water tanks and standard plumber piping. About 2'500 of these biogas plants are in use in India (Müller, 2007) and they are currently being promoted by local NGO's in Tanzania and Uganda (Lohri, 2009).

- **Tube/bag digesters**

The tube reactors also called 'balloon plants' or 'plastic bag digesters' were developed to avoid having to build the labor intensive brickwork. The tube digester consists of a plastic or rubber bag (e.g. PVC) in the upper part of which the gas is stored. The inlet and outlet are attached directly to the skin of the balloon. The gas pressure is achieved through the elasticity of the balloon and by added weights placed on the balloon. Safety valves are required to ensure that the gas pressure doesn't exceed the limit that the balloon can withstand. Since the material has to be weather- and UV resistant, specially stabilized, reinforced plastic or synthetic caoutchouc is given preference. Other materials which have been used successfully include RMP (red mud plastic), Trevira and butyl. The useful life-span does usually not exceed 2-5 years (ISAT/GTZ, 1999). Tube digester can be considered as 'quasi-PFR' if TS is high.

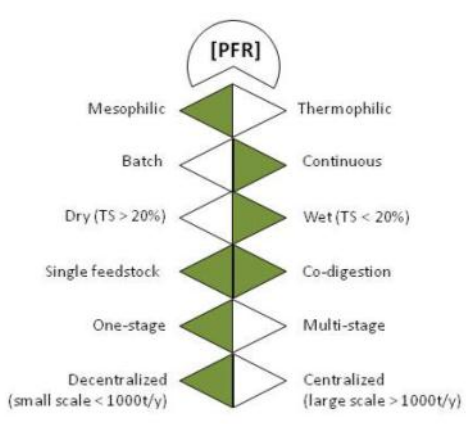


Figure 31: Characteristics of tube technology

Advantages
- Standardized prefabrication at low cost
- Shallow installation suitable for use in areas with a high groundwater table

- High digester temperatures in warm climates
- Ease of transportation
- Low construction sophistication
- Uncomplicated cleaning, emptying and maintenance (ISAT/GTZ, 1999).

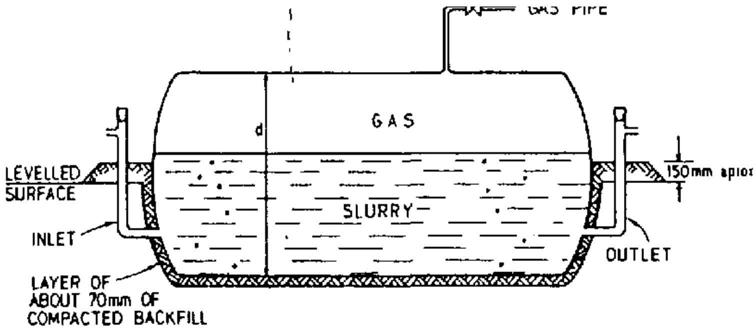


Figure 32: Schematic of tube digester [14]

Disadvantages
- Relatively short life span
- Low gas pressure may require gas pumps
- Scum cannot be removed during operation
- High susceptibility to mechanical damage
- Local craftsmen are rarely in a position to repair a damaged balloon
- Little creation of local employment
- If solids content is low, problems with floating and settling layers are expected, resulting in too low HRT (ISAT/GTZ, 1999).

The above described three digester types are inexpensive, built with locally available material, easy to handle and do not have many moving parts prone to failure.

In developing countries, biogas is generally more accepted by upper and middle-income farmers. In countries in Asia, Africa and Latin America, the cases of non-technical reasons for failure make about 50% of the total. Other site-specific issues affecting biogas production and commercialization in sub-Saharan Africa include the availability of water for dilution and organic materials for effective biodigester operation. The principal reason is that real acceptance of biogas technology depends on individual interests that do not totally respond to those at the national level. This suggests the necessity of fully understanding the individual interests of a project. Small-scale biogas plants are located all over the African continent but very few of them are operational. There is thus a need to introduce more efficient reactors to improve both the biogas yields and the reputation of the technology (Parawira, 2009).

Gebren & Oelofse (2009), who looked at the potential of unlocking the resource potential of organic waste in South Africa, explain AD technology failures in developing countries as follows:
- Education and skill level of plant operator
- Maintenance problems with complex and expensive systems/equipments
- Technical and financial constraints
- Social considerations
- Infrastructure requirements

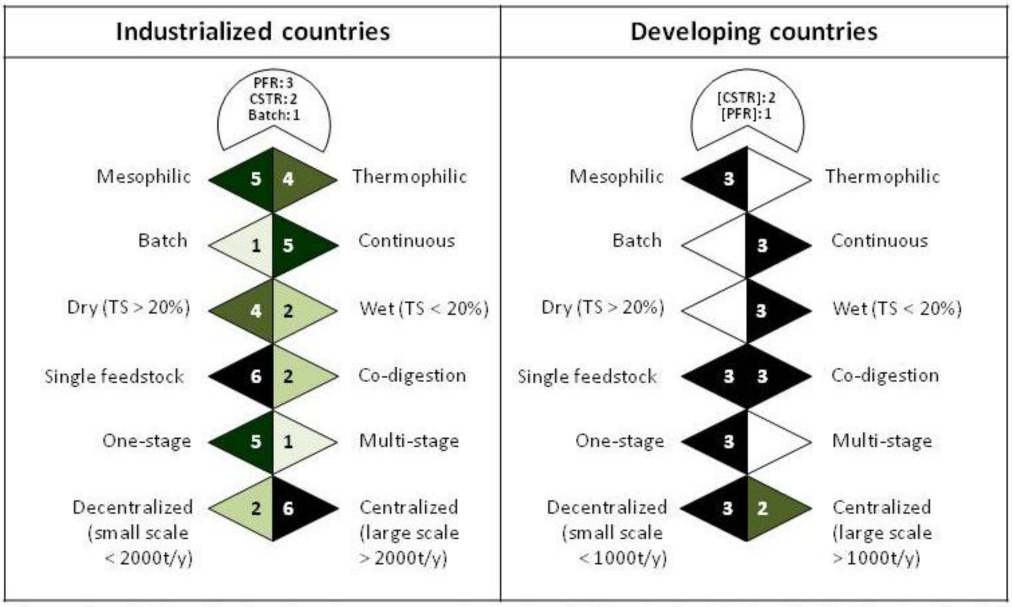
In their opinion, whether the resource potential of organic waste will be unlocked in South Africa is largely dependent on an enabling governance environment, including national legislation and on the priorities of both the environmental and energy sectors.

China and India have extensively utilized biogas as a source of energy and as liquid fertilizer for soil enhancement since the 1950s. The main driving forces in these countries have been a combination of several factors which include national biogas development programmes financed and supported by the governments, restriction of using landfill, the taxes on CO_2 and other emissions, effective environmental legislations, advanced research, development and demonstrations and public acceptance of the biogas technology particularly due to its environmental benefits (Parawira, 2009).

According to Mshandete & Parawira (2009), the development of large-scale anaerobic digestion technology in Africa is still embryonic, although the potential is there. They see a need to learn from the past experiences and adapt biogas technology from Europe and Asia for local circumstances through research. Their argument is that basic research is still needed mostly on the quantity and potential biogas yield of fermentable organic wastes available and the size and type of digesters which can be economically viable for potential customers of the biogas technology. There is little or no (laboratory research-based) information on biogas technology research in most African countries, which could be one of the factors contributing to poor biogas technology application in Africa.

In May 2007 the 'Biogas for Better Live - an African Initiative' was launched in Nairobi, Kenya. The purpose of this initiative is to provide 2 million households in rural Africa with domestic biogas plants (Boers, 2008). The initiative is supported by SNV Netherlands and KfW Germany and has resulted in a number of positive spin-off effects on anaerobic digestion technology in terms of value added products from organic wastes in the form of biogas and biogas manure (Mshandete & Parawira, 2009). The initiative covers a number of countries in sub-Saharan Africa such as Benin, Burkina Faso, Cameron, Ethiopia, Ghana, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Niger, Rwanda, Senegal, Tanzania, Togo, Uganda, Zambia, Gambia and more. Nevertheless, as far as biogas and anaerobic technology is concerned, South Africa is unique in sub-Saharan Africa because of its high level of economic development and many universities with state-of-the-art research capacities (Mshandete & Parawira, 2009).

Comparison of technological characteristics of described AD technologies in industrialized and developing countries: The introduced AD technologies from the sections above are presented in a summarized form in Figure 33. Although only representative to a limited extent (only the above described technologies have been taken into consideration), the figure still reveals interesting differences. It can for instance be seen that all three technologies widespread in developing countries (fixed-dome, floating-dome, tube digester) show the same technological characteristics (with the exemption that not all can be applied on large-scale). They all use wet (strongly diluted) feedstock, are continuously fed, set-up as a one-stage system and are suitable for co-digestion (for instance addition of human excreta). In order to promote the digestate use as fertilizer, the issue of pathogen reduction (post-treatment steps) needs to be closely looked at. The described AD technologies for treatment of biowaste in high-income countries predominately use dry fermentation technologies and plug flow reactors (PFR). In the developing country context, external heating of the digester is hardly ever an option due to climatic conditions, unfavourable energy balance on such small scale and associated financial issues. In industrialized countries, thermophilic digestion is an interesting option due the higher gas yield, the availability of electronic devices to control the AD process, and because the larger scale (centralized systems) shifts the energy balance in a favourable direction.



The numbers indicated in the triangles represent the number of AD technologies (described in this thesis) which show this characteristic (some of the technologies are suitable for different attributes).
In total 6 AD technologies for biowaste were described that are widespread in industrialized countries, while 3 AD technologies were presented that are widespread in developing countries.

Figure 33: Comparison of AD technology characteristics in high-income and low-income countries (based on selected technologies described in 5.3.1 and 5.3.2)

5.4 AD in Ethiopia

5.4.1 AD development in Ethiopia

Anaerobic digestion technology was introduced in Ethiopia as early as 1979, when the first batch type digester was constructed at the Ambo Agricultural College. In the last two and half decades around 1'000 biogas plants, ranging in size from 2.5m^3 to 200m^3 were constructed in households, community and governmental institutions in various parts of the country. In 2008, approximately 40% of the constructed biogas plants were not operational anymore due to lack of effective management and follow-up, technical problems, loss of interest, reduced animal holdings, evacuation of ownership, water problems etc. Consequently, domestic biogas does not have a favorite reputation in Ethiopia and there is widespread skepticism amongst biogas experts to unleash the potential for biogas in Ethiopia that could potentially be beneficial to hundreds of thousands households (Boers, 2008).

In 1991 the Ethiopian Electricity Agency (EEA) reported 103 biogas installations that had been constructed by nine different institutions /organizations. Early 2000, reports mentioned less than 350 household digesters (up to 30m^3), a small number of institutional biogas installations (up to 100m^3), 6 community biolatrines and 4 bio-digester septic tanks. In addition, EREDPC (Ethiopian Rural Energy Promotion and Development Centre) mentioned the introduction of the cheaper 'plastic bag' biogas plants. Recently, World Vision Ethiopia introduced biogas under its Appropriate Agricultural Technology Promotion Initiative. In 2006, 150 plants had been constructed (or were in process of being so). All in all, the total number of domestic biogas plants was estimated to be in the range of 600 to 700 installations (Eshete, Sonder & ter Heegde, 2006).

- **National program for domestic biogas in Ethiopia (NBPE)**

The National Biogas Programme Ethiopia (NBPE) was started in 2007 by SNV in cooperation with the government of Ethiopia. Goal and purpose of the NBPE is to improve the livelihoods and quality of life of rural farmers through exploiting the market and non-market benefits of domestic biogas using cattle dung as feedstock (Eshete, Sonder & ter Heegde, 2006). In the first phase of the implementation (5 years) it is planned to construct 14'000 biogas plants with a potential to up-scale construction to 100'000 in the next phase (Boers, 2008). The NBPE intends to lay out a robust foundation for the establishment of a commercially viable domestic biogas sector, thus involvement of stakeholders is essential. It is particularly important to involve the governmental authorities; as their influence is immense and thus their support is of very high relevance (Boers, 2011). In numerous multi-stakeholder workshops at the early stage of the NBPE, participatory decision were made. Among others, it was agreed that exclusively the standardized design of the SINIDU (Amharic: ready) model, a type which is based on the Nepali GGC 2047 model, in the sizes 4, 6, 8 & 10m^3 will be implemented under the national biogas program.
Furthermore, the stakeholders identified the Ethiopian Rural Energy Development Centre (EREDPC) at the national level and the Mines and Energy Agencies (MEA) at regional level as the lead institutions with a regulatory responsibility. According to Boers (2011), SNV had argued in favour of the Ministry of Agriculture due to the often underestimated value of digestate, but also because it feared that the Ministry of Energy & Mines would not give sufficient attention to domestic biogas in comparison to the much larger national hydropower projects. In October 2011, 1'800 AD systems have been built under the NBPE of which 95% are operational (Boers, 2011). In Amhara state, by the end of August 2011, 294 AD systems had been constructed, all between 6 and 10 m^3 in size (Kada, 2011).
Approached on the subject of problems, Boers (2011) mentioned that research activities proceed rather slowly and workmanship could still be improved.

In terms of institutional AD systems, SNV is receiving frequent requests by the Ministry of Energy to become active on this scale as well. However, although admitting the large potential of institutional AD in Ethiopia, SNV has not started activities in this field as the domestic NBPE still requires its full attention (Boers, 2011).

According to Kada (2011), most of the built institutional AD systems in Ethiopia are currently non-operational due to a lack of user-trainings, follow-up and maintenance services and in general a lack of institutional capacity. SNV in their construction trainings teach how to build the SINIDU model up to 15m^3.

Some training participants later on decide to offer construction of institutional AD systems (up to $100m^3$) without being aware that this increased size requires essential structural modifications like reinforcement of the gas dome by iron elements. This leads to poor quality of institutional AD plants while at the same time casting a bad light on SNV as it has trained the constructors. While SNV has established a severe quality control system for constructors with a license to build domestic AD systems as part of the NBPE, such control & monitoring system is absent in the case of institutional AD systems (Kada, 2011).

5.4.2 AD projects of biowaste in Ethiopia

- **SAWE project by LEM Ethiopia (Bahir Dar)**

Figure 34: SINIDU fixed dome underground model promoted in SNV's NBPE

LEM (Amharic: some fertile thing), the Environment & Development Society of Ethiopia, is a citizen's movement inspired by the concepts of sustainable development and established in March 1992. In January 2009 LEM Ethiopia in Bahir Dar with external support from the Ministry for Foreign Affairs of Finland started the project 'Improvement of self-sufficiency and sustainability in sanitation waste and energy project in Bahir Dar (SAWE)'.

The overall objective of the project is to alleviate the poverty and improve environmental sanitation and waste management situation of the city of Bahir Dar. The specific objectives are: a) Enhanced community awareness, knowledge and participation of urban dwellers in solid and liquid waste management; and b) Reduced health hazards caused by poor sanitation situation in the selected four kebeles. The project includes among others the formation of unemployed youth groups and their establishment as small micro enterprise cooperative societies, a mobile dry toilet on the market, urban agriculture and the construction of two integrated sanitation facilities in kebele Gis Abay and kebele Fasilo. One integrated sanitation facility consists of a building with 2 showers and 4 toilets, the toilets are connected to a $15m^3$ AD system (SINIDU model), a cafeteria that uses the biogas produced from human and kitchen waste for boiling tea and coffee water and cooking snacks. The cafeteria will be managed by the above mentioned youth group (Hunegnaw, 2011).

Construction of the integrated sanitation facilities has started but the implementation process was delayed due to different reasons: In kebele Gish Abay, although the construction of the AD system is completed, the facility is not yet operational due to a dispute between kebele administration, community and LEM about the demolition of the old poorly managed former latrine in front of the building. The construction of integrated sanitation facility in kebele Fasilo was interrupted because of the resign of the contractor due to shortage/high price of cement. A new contractor started his work but the quality of construction is unsatisfactory and the AD system thus not operational yet (LEM, 2011).

Figure 35: LEM Ethiopia Integrated sanitation facility in kebele Gish Abay. Left picture: New sanitation facility with old latrine (left) and AD system (right of the building). Right picture: Showers and toilets

Interview with the constructor of the LEM Ethiopia AD systems, Mr. Molla revealed that he is not interested in giving trainings to enable the users of the systems to do maintenance and repairing work themselves. He argued that this would mean a loss of potential income for him as the institutions then do not need his expertise anymore. In case of problems or failure of an AD system, he prefers to be contacted and asked to fix it himself because this means additional work and salary for him.

- **Felege Hiwot Hospital (Bahir Dar)**

In 2005, an underground biogas system for treatment of human waste was constructed in the public hospital Felege Hiwot in Bahir Dar. According to the person responsible for sanitation issues on the hospital campus, nobody of the current staff has knowledge about the AD technology and the responsibilities for operation (feeding) and maintenance work are not clearly allocated. The following information were collected which could not be 100% confirmed due to lack of design plans and reliable sources. It was mentioned that the AD system in Felege Hiwot, installed with financial support of a Spanish NGO, is a 65 m^3 fixed dome underground model with brick walls. 8 toilets, which are used by an average of 300 persons/day, are connected to the digester. Additionally, kitchen waste and some cow dung are also added regularly. The kitchen staff reported that they used to be able to cook for 7 hours/day with the generated biogas. However, currently the daily biogas produced is only sufficient for 2 hours of cooking. The digestate is directed into a field of uncontrolled growing plants. According to the interviewed persons, no training and no regular maintenance work had been conducted in recent years.

Figure 36: Felege Hiwot hospital: Inlet with kitchen waste, underground AD system, biogas stove, biogas flame (left to right)

- **West Gojam Prison (Bahir Dar)**

In 2004, an underground fixed dome biogas system (100m^3) was constructed in West Gojam prison in Bahir Dar with the involvement of the International Committee of the Red Cross (ICRC) (AG consultant, 2007). The number of detainees varies between 1’700 and 2’100 persons, of which 50-60 are females. At the time of visit in October 2011, the AD system, which is still connected to the toilet facilities, was not operational anymore: According to information of the prison staff and detainees, the system had stopped working about two years ago due to unknown reasons. Although the main valve is closed, biogas still leaks through the gas pipe. This gas is released in front of the kitchen where the kitchen staff had disconnected the pipe. They explained the reason for disconnection with the insufficient amount of gas reaching the kitchen. Since human excreta of the prisoners still enter the digester, the AD process is still active. This implies that biogas is currently still produced and emitted to the atmosphere, thereby imposing a risk to the detainees’ health. Lack of finances, knowledge, skills and maintenance were mentioned by prison staff and detainees when asked about the main problems they had faced with the installed AD system.
According to the report by AG consultant (2007), the persons responsible for operation and maintenance of the biogas plant were trained inmates, but knowledge and skills were lost when these persons were released. The report gave recommendations to continuously train inmates as well as prison administration staff in system management to avoid the loss of skills by released prisoners.

Visit to the Regional Prison Commission revealed their lack of interest and capacity to intervene and repair the systems. It was mentioned that about 10 AD systems in Amhara state exist but hardly any of them are functional anymore. This information was given without further details. The interviewees agreed that lack of knowledge, training, capacity and finances are the main problem and that ICRC is no more involved in AD projects in prisons of Ethiopia. In addition, the responsibility over the AD system within the prison’s staff is usually given to an agricultural expert who does not have sufficient AD knowledge.

- **Biogas project on polytechnic campus of University (Bahir Dar)**

The faculty of engineering on the polytechnic campus of Bahir Dar University started planning the construction of an AD system for treatment of human and kitchen waste in 2007. For this purpose, a techno-economic feasibility study was conducted in 2008, to provide recommendations in terms of location, type, and dimensioning of an AD system for the human and kitchen waste generated by 1000 students. The report recommended the construction of a 100m^3 fixed dome digester (Ashagrie, 2008). However, due to an increase in students' numbers and the new intention to build an improved, more efficient AD technology that allows scientific experiments, the project has been interrupted (Nigus, 2011).

- **Medhani-Alem Preparatory School (Addis Ababa)**

The EPA in 2010 selected the governmental school of Medhani-Alem in Addis Ababa (3'600 students) to receive an AD system for treatment of human and kitchen waste. ThiGro Power Cooperative won the tendering and in 2011 started construction of the 16m^3 fixed dome SINIDU model (brick masonry). One toilets block in 100 m distance to the AD system is connected to the digester. The idea was that 30% of all students use these toilets, adding a daily amount of 0.5 kg feces/person. To ensure a hydraulic retention time of 50 days and to prevent over-dilution of the substrate, the flushing of human excreta is not done individually by the toilet users. It was planned to flush the toilets only once per day in the evening by the school cleaning team (Dejene, 2011). At the time of visit in October 2011, the toilet block was locked due to repairing work. No substrate entered the digester, thus hardly any biogas was produced that could be used in the kitchen of the staff restaurant. The kitchen workers reported that in the first 5 months after construction, they could use the biogas stove for about 5-6 hours per day for cooking. But due to summer holidays (2 months), no students were using the toilets, thus biogas production decreased to a minimum.

The conducted interviews revealed a problem of distributed responsibilities, uncoordinated tasks and lack of knowledge about the complete AD chain: The cleaning team was responsible for cleaning and flushing of the toilets, as well as for collection and disposal of solid wastes generated on the school campus. But it was not informed about the possibility of adding kitchen waste to the digester to increase biogas production. The kitchen staff was not aware about the maintenance requirements of the system (e.g. emptying condense water) and thus was not able to react in case of minor problems. The safety guards of the school were involved in agricultural activities on the school campus, but were not properly informed about the risks and benefits of using the digestate as fertilizer. The students using the toilets often flushed their excreta with additional water because they were not aware about the consequences of their actions on the AD system.

- **Holland Car Company (Addis Ababa)**

Ethiopia's first indigenous vehicle assembly company Holland Car in Addis Ababa had plans to start producing and selling biogas powered cars in Ethiopia. The goal was not only to assemble biogas-fueled vehicles, but to also produce the biogas from municipal organic waste itself. This intention was broadcasted on BBC and received considerable attention. When visiting the Holland Car Company in October 2011 the person responsible for Holland's biogas car project explained that the ambitious project was stopped due to several reasons: Apart from a lack of funds, there was also very limited capacity because the head of Holland Car's research and development department had returned to the USA. Holland Motor's first 'biogas-driven' car as shown in the media was a car imported from China with a hybrid engine i.e. can run on biogas or on gasoline. However, since no biogas bottles had been imported from China, this car never actually ran on biogas while in Ethiopia. Not only the required upgrading of biogas to make it suitable as vehicle fuel constituted problems, but also the collection and pre-treatment of municipal organic waste as substrate for biogas production revealed substantial logistic problems.

- **IGNIS project (Addis Ababa)**

IGNIS (Income generation & climate protection by valorizing municipal solid wastes in a sustainable way in emerging mega-cities) is a research and demonstration project of the German Federal Ministry of Education and Research. One of the activities within the IGNIS project is to test the operation of a pilot AD system using canteen waste from the Institute of Technology (University Addis Ababa).

This high-tech system is composed of a delivery storage cylinder (1.5 m^3) made from stainless steel equipped with a sensor for overflow prevention. After shredding and mixing, the substrate is fed with the help of an eccentric snail pump into the fermenter (15 m^3), which is an insulated cylindrical tank inside a container frame. The automatically mixed fermenter content is heated making use of solar panels and electricity. The produced gas is stored in a gasholder balloon (8.8 m^3). By using a daily input of 200 kg of kitchen waste and 400 kg of kitchen waste water, this biogas plant aims at producing 28,7 m³ of biogas per day, which shall be directly used by the kitchen for cooking and to provide hot water for dish washing.

Figure 37: IGNIS pilot biogas plant in Addis Ababa

According to the person responsible for the start-up and operation of the system, the problems are manifold (Panse, 2011): The motivation of the main stakeholders in participating in the project is very small. Particularly difficult is the fact that the interest of the university professor with expertise in AD is rather limited, which results in a lack of an organizational leverage. The AD technology is considered not suitable for the local context due to its complexity and unavailability of spare parts in Ethiopia. As a result of these issues, the project has been delayed considerably and support of its operation is gradually decreasing even more. The kitchen staff for instance, who has an important role within the AD chain by providing biowaste from the kitchen and using the produced biogas for cooking, is more and more showing a disruptive interest in the project. They demand an extra salary of 50 ETB/day/person to bring the substrate from the kitchen to the adjacent digester (roughly 30 min of work/day). This budget point has not been considered by the project coordinators and presents a growing obstacle for sound operation of the system. In addition, the electrician also started claiming extra money (20'000 ETB) for maintenance work and the lab assistants for testing the samples. The increasing demand for extra salaries seems to underline the absence of careful involvement and agreement with stakeholders during preparatory stage of the project.

- **Other AD projects**

During the evaluation conducted by AG consultant in 2006, 22 institutional AD systems funded by LCF (Local Cooperation Funds) were inspected. These AD systems fall into four categories of user groups (schools, urban community, farmers' milk units and prisons). A summary of the visited projects indicates that 50% of the evaluated systems resulted in improved sanitation, 30% still generate biogas and only 20% of the units use the slurry from the biogas digester.

The farmers' milk units' biogas digesters were observed to be a predominant failure, only two out of nine biogas digesters still generated biogas and the work of most units was not completed. The majority of visited biogas digesters in prison were successful. After the first introduction in Addis Zemen prison in 2003 had proved a success, more than a dozen prisons have followed and installed a biogas digester. Experiments in schools have been a failure due to operational problems. High staff and student turnover results in lack of dedicated attention to follow up on the system. The high cost of biogas digesters was spelt by many stakeholders as a hindrance to its promotion.

Limited awareness of AD technology by project implementing NGOs, the beneficiary community, school administration and prisons administration in the program was observed. Major problem in most of the visited AD projects was incomplete works, absence of maintenance service and monitoring, lack of water and feed availability, lack of training and associated awareness, and absence of dedicated personnel to manage the biogas digesters (AG consultant, 2007).

According to Kada (2011), an EU funded project tried out ten tube digesters in the Awaza region in 2009. Various problems have been observed in this experiment. Among others, the sensitive plastic was frequently damaged by chicken, rats and sunlight and the gas pressure was too low. Although inexpensive, the results of these experiments lead to the conclusion that tube digesters are not an appropriate technology for the Ethiopian context as it is not a robust technology. However, Kada (2011) also remarked that he has not received the latest information about the outcome of this project.

- **Encountered problems and lessons learnt from AD projects in Ethiopia**

The encountered main issues of concern, experienced problems and given recommendations in the Ethiopian context of urban AD projects are summarized in the following list based on the above described projects:

- Governmental authority are major stakeholders in AD projects due to their immense influence
  → It is inevitable to include governmental authorities, even if they are not directly and actively involved in the AD project.
- Research activities need special attention as they generally proceed rather slowly.
  → Official contract agreement with clearly stated research activities, expected outputs and deadlines are recommended.
- The sharp rise in cement prices has to be taken into financial considerations.
  → Precise cost calculations using most recent prices of materials are crucial in pre-project stage.
- High cost of biogas digesters as a hindrance to its promotion.
  → The funding conditions need to be looked at carefully.
- Underestimated logistic efforts for substrate collection.
  → A chain-perspective is important when organizing the substrate for the AD system. This will increase the chance of a smooth collaboration of all actors involved in the substrate chain.
- Involvement of stakeholders in the preparatory stage of the project is important and agreements need to be worked out stating the precise responsibilities (and related salaries) for the tasks.
  → Involve stakeholders as early as possible in the pre-projects stage to build a broad fundament of support for the project. Make sure that workers receive fair payment for their contribution.
- Disruptive interest of relevant stakeholders can threaten sound operation of the project.
  → Be aware of disruptive attitudes of any (but particularly major) stakeholder. Understand the reasons and try to find ways to reduce or eliminate them.
- Workmanship can still be improved.
  → Continuous trainings and supervisions are important.
- Small-scale domestic systems are up-scaled to institutional level without the necessary technical adaptations (e.g. reinforcement of dome).
  → Trainings for large-scale (institutional) AD systems are necessary. During trainings for small-scale (domestic) systems, the problems with up-scaling have to be mentioned.
- Loss of design plans of underground systems lead to lack of knowledge about size of digester, location of pipelines and water traps etc.
  → It is important to keep extra designs and plans (hard and soft copies) of the AD system.
- Limited awareness of AD technology was observed of project implementing NGOs, the beneficiary community, school administration and prisons administration in the program.
  → Trainings and workshops are of crucial importance, demonstration systems and user manuals can help to raise awareness.
- Lack of institutional capacity lead to absence of institutionalized user-trainings and systematic control-, monitoring and maintenance work. This poses a threat to long-term operation of AD projects.
  → Knowledge and skills of implementing companies have to be controlled. Licensing is one possible option, a fixed monitoring and maintenance strategy for each AD is inevitable.
- Some AD constructors are not interested to give maintenance trainings to users because of fear to lose regular work and salaries. In that sense they welcome small technical problems because it means they are asked to come and do repairing work.

→ Again, licensing can help to ensure certain quality of work and inclusion of user-trainings and maintenance services.

- High prison staff and student turnover results in lack of dedicated attention, knowledge and skills to follow up on the system. If capacity is limited to a few people only, knowledge is lost when trained/knowledgeable persons leave the institution (e.g. Holland Car Company).
  → Regular trainings and workshops allow knowledge transfer; fair payment of extra work motivates people to take up extra responsibilities.

- Responsibility of AD operation is with agricultural experts who lack technical AD knowledge (prisons).
  → Technical-mechanical experts need to be in exchange with agricultural experts. An AD system produces two valuable products, both should receive similar emphasis.

- General interest of academic institutes to conduct scientific research on AD system.
  → Ensure that the AD system is academically accompanied by a research institute. Scientific research through regular sampling and data collection will increase chances for sound operation and in case of failure, the reasons can be evaluated.

- Involvement of academic institutes is recommendable for scientific supervision. However, appointment of an interested, influential and competent local lead coordinator is crucial for adequate allocation of tasks and enforcement of good progress.
  → Contract agreements are helpful as the officially stated mutual expectations can serve as basis for discussions (and solving of conflicts).

- Problem of distributed responsibilities, uncoordinated tasks and lack of knowledge about the complete AD chain.
  → Stakeholder coordination is crucial. Overview over whole AD chain is important to know where to intervene in case of troubles. Stakeholders need to be motivated (they need to see and have a benefit from their contributions).

- High tech system: Unsuitable if there is a lack of interest, specific knowledge and spare parts.
  → Proposed AD technology needs to be appropriate, feasible and sustainable in correspondence to the local circumstances. Pilot project on small-scale of a new, highly advanced technology is necessary to test suitability for local context. Spare parts need to be available nationally or a stock of most sensitive parts needs to be organized in advance.

- To sum up, the major problem in most of the observed Ethiopian AD projects was incomplete works, absence of monitoring, lack of water and feed availability, lack of training, associated awareness and maintenance service, and absence of dedicated personnel to manage the system.
  → A detailed feasibility study can help to maximize the chances that work will be completed, monitoring and maintenance strategy is developed, substrate, water and material is available, and involvement of relevant stakeholders are included already at an early stage.

These recommendations are taken into consideration for elaboration of the feasibility assessment tool.

6 Feasibility assessment tool for urban anaerobic digestion

6.1 The tool at a glance

Figure 38 presents the scheme of the feasibility assessment tool. Based on the ISWM and UN Habitat frameworks, (Figure 1) the tool is grouped into four dimensions that correspond to the four influencing factors in urban AD projects. Each dimension answers a specific question about the proposed AD project. The complete framework in Excel form with all questions of the feasibility assessment tool can be found in Appendix VII and VIII.

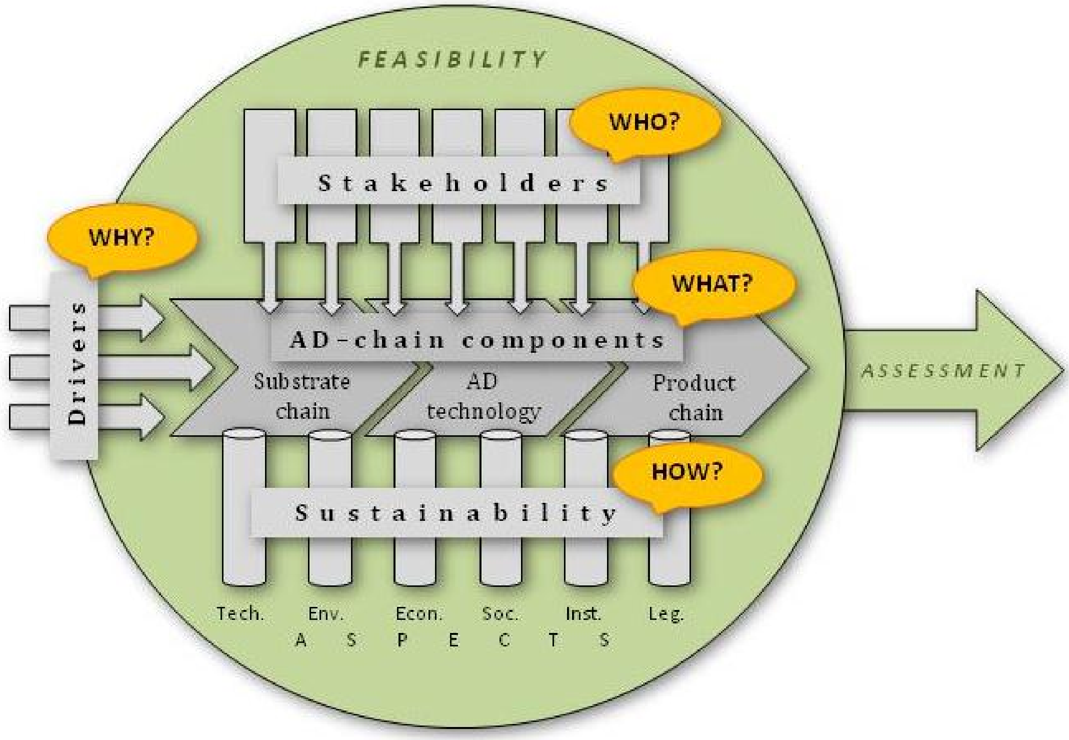


Figure 38: Scheme of the feasibility assessment tool for urban anaerobic digestion in developing countries

The tool is designed to be used by a stakeholder with certain in-depth AD knowledge who wants to assess the feasibility of a proposed AD project. It is important to note that the tool needs to be fine-tuned for each context in order to suit the specific circumstances in which it is applied.

a. The person conducting the assessment answers a set of questions within each dimension; consultation with other stakeholders is absolutely necessary to get all relevant information.
b. The first three dimensions (Why? Who? What?) ask for answers of descriptive nature and aim at delineating the context and set-up of the proposed AD project.
c. The fourth dimension (How?) constitutes the actual feasibility assessment and presents three pre-set answer categories that translate into scores (not feasible: -10, neutral: 0, very feasible: +10). These scores form the basis of a feasibility matrix, which is the main working document of the assessment.
d. Stakeholders are asked to give weights to the main groups of feasibility criteria to reflect their relative importance in the outcome of the project.
e. A separate set of questions is given to allow defining the uncertainty range for each criteria group.
f. The results of the feasibility assessment are at the end visualized in two different figures.

The performance of the feasibility assessment tool is described in more detail in chapter 6.3 Instructions for use of feasibility assessment tool (Excel).

Checking points are placed at certain positions within the course of questions. These checking points consist of key questions or issues which aim at exposing constellations that are supportive, neutral or disruptive for the AD project. Answering the question of the checking point with ‘supportive’ or ‘neutral’ means that it can be carried on with the next part of the tool.

If the answer to the key question is 'disruptive' a red flag occurs (Figure 39), which signifies: Attention, potential project breaker! In such case, an intervention is required i.e. the issue needs to be addressed, cleared or improved in collaboration with the respective stakeholders before continuing with the tool.

Figure 39: Symbol of potential AD project breaker: Red flag

In the fourth dimension (How?), every question answered with -10 requires individual attention. It needs to be examined if the issue under this question is in itself a potential project breaker.

The idea behind the first visualization figure is to create a simplified presentation of the feasibility assessment results that illustrates the most important strength and weaknesses of the proposed AD project. Each main feasibility category is represented by a bar, whose direction and length indicates the level of feasibility. It combines/factorizes the experts' score and the stakeholder's weight. A bar that goes up to +100 stands for very feasible, a bar that goes down to -100 implies that the project is not feasible at all in regard to this sustainability criterion (red flag). In addition, *the uncertainty range (grey zone) is* illustrated to depict the risk of deviated outcome compared to the expectations according to the scores. Figure 40 presents a visualization example of an imaginary AD project.

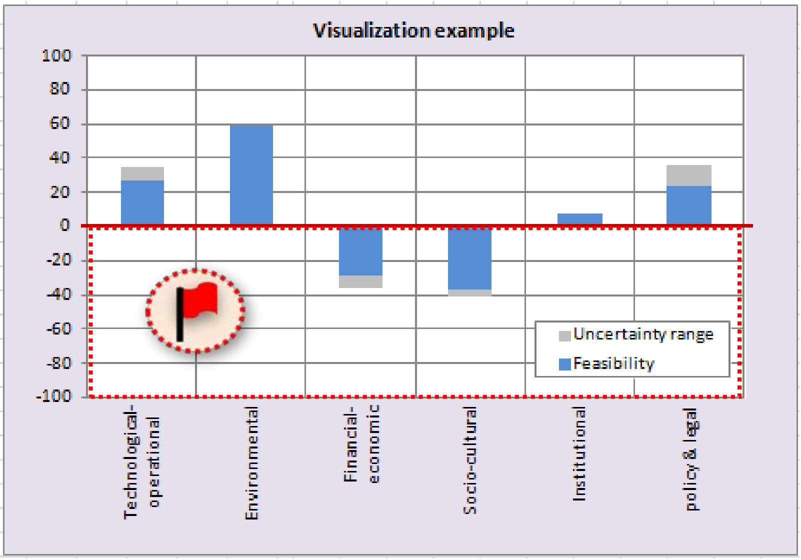
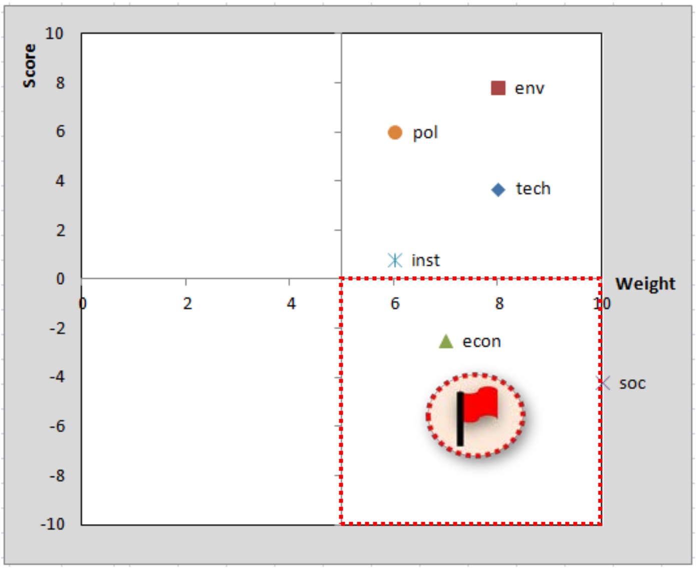


Figure 40: Visualization example of feasibility assessment result by one fictive AD project

The second visualization figure presents the feasibility of an AD project from the perspective of a stakeholder (Figure 41).



The scores are presented on the y-Axis, while the explicit weights given by the stakeholder are shown on the x-Axis. This allows comparison between the relative importance of different stakeholders for each criterion.
A red flag is positioned in the bottom-right quadrant, where the assessed sustainability criteria scored negatively while at the same time this category is considered to be very important for the success of the AD project.

Figure 41: Visualization example of feasibility assessment result of a fictive stakeholder in an imaginary AD project

6.2 Four dimensions of feasibility assessment tool

6.2.1 WHY? (Drivers and motivations)

The first dimension is an introductory part intended to expose driving forces and motivations of the main stakeholders (project initiators, funding agencies and local authorities). It aims at making them aware of each other's priorities and facilitating cooperation based on clear drivers and goals.

This dimension contains the following set of questions:

1.1 Motivation behind the AD project

- What were the motivations of the initiator(s), funding agencies and local authorities to start this AD project? (Drivers of other stakeholders are discussed later under 2.1)

1.2 Social driver (Public awareness or pressure from other stakeholders)

- Was public awareness or pressure from other stakeholders (e.g. NGOs, universities, national government, funding agencies) one of the main reasons for the initiation of this AD project?
- If so, when, how, by whom and why specifically was such pressure exerted?
- Are there ongoing activities related to the AD projects for promotion of AD of biowaste as a result of public awareness or pressure from stakeholder groups?

1.3 Environmental driver (Resource recovery for environmental sustainability)

- Was recovery of resources (energy, nutrients) one of the main reasons for the initiation of this AD project?
- If so, when, how and by whom were resource recovery activities started and what specifically was such resource recovery aimed at (e.g. need for locally available energy source, saving forests as source of firewood, availability of large amounts of organic waste)?
- Are there ongoing activities related to the AD project for promotion of AD as a means to recover resources (energy, nutrients) from organic waste?

1.4 Economic driver (Financial considerations → Valorisation of resources)

- Was valorization of resources one of the main reasons for the initiation of this AD project?
- If so, when, how and by whom were valorization activities started and what specifically were the specific financial considerations/intentions behind starting the AD project?
- Is AD of biowaste part of a broader program/set of activities aiming at valorization of resources?

1.5 Other drivers

- Were there any other activities/developments (e.g. tourism, institutional changes, political or academic interest) as important drivers for this AD project?

1.6 Summary of main drivers and motivation for AD project

- List the main development driver for the AD project under assessment. Group the drivers into social, environmental, economic and other categories.

6.2.2 WHO? (Stakeholders in AD system)

It is important to know all relevant stakeholders in the AD system. Thus the following set of questions help identifying and characterizing them:

2.1 AD-Stakeholders

- Who are the stakeholders in the system of the proposed AD project (i.e. who has an interest in AD, who is positively or negatively affected by it)?
- Most AD projects encompass the following groups of stakeholders. The list can be used to ensure that no relevant stakeholder is forgotten:

  1. Funding agency
  2. Governmental authorities
  3. Waste generators
  4. Design and installation specialists
  5. (Future) operation & maintenance staff
  6. End-users of AD products
  7. Legislator and enforcement agencies
  8. Research institutions
  9. National and international NGOs
  10. Site residents (if any)

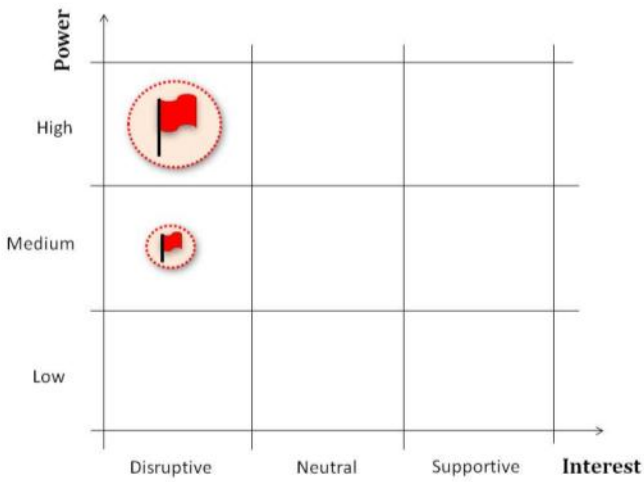
- What role does each stakeholder have in the AD project?
- What power (low, medium, high) does each stakeholder have in the AD project?
- What interest (disruptive, neutral, supportive) does each stakeholder have in the AD project?
- What are each stakeholder's individual drivers in the AD project?
- What are each stakeholder's means of interventions (i.e. how is their influence practically expressed) in the AD project?
- The following filled out table provides an overview of the stakeholders in the AD project

Table 14: Template of table to characterize the stakeholders of the AD project

Stakeholder	**Role**	**Power** *High Medium Low*	**Interest** *Supportive Neutral Disruptive*	**Individual drivers**	**Means of intervention**
A					
B					
C					
…					

2.2 Summary of stakeholders in AD project

It is of particular interest to find out the level of power (control) of a stakeholder over the proposed AD chain and in addition to check if the stakeholder's interest related to the AD project is supportive, neutral or disruptive.



This is the first **checking point** in the tool: Are there stakeholders with medium or high power that show a disruptive interest in the AD project?

If so, a red flag occurs. A matrix as presented in Figure 42 can be helpful to reveal unfavourable conditions (red flags) for the AD project.

Figure 42: Power-interest Matrix to reveal disruptive stakeholder constellations (red flags)

6.2.3 WHAT? (Physical components & flows in AD chain)

The relevance of this dimension is to provide precise information about the physical components and flows *as proposed in the AD project under assessment*. The questions of this part are structured into the following three groups:

3.1 Substrate chain

- Description of the required substrates (sources, quantities and qualities) for AD project as proposed
- Substrate availability (+ seasonal variations incl. reasons, extents and consequences of changes)
- Dry matter (TS) and organic content (VS) of organic substrate groups as proposed for the project (if data on VS is not available, use of literature figures)
- Description of proposed collection of AD substrates and transport (incl. distance) to AD site
- Inventory of staff and equipment for proposed substrate collection
- Means of primary collection/transport from source to collection points (if any) or directly to AD site
- Means of secondary collection/transport from collection point (if any) directly to AD site
- Frequency/intervals of substrate collection from households, institutions, commercial clients, collection points and transport to AD site as proposed in the AD project under assessment?

3.2 AD Technology (incl. pre-treatment & post-treatment)

- Description of the proposed AD technology (AD-system, operating parameters [pH, temp., HRT])
- Description of location and required space
- Range of substrate amount needed for sound operation (per day) of proposed technological set-up
- Range of daily substrate quality needed for sound operation (purity/VS)
- Required daily water quantity (for dilution and general operational practices)
- Proposed pre-treatment steps for substrate (sorting, shredding, mixing, etc.)
- Energy requirements for operation of AD system (e.g. for pumps, mixing devices, temp. regulation)
- Expected gas yield (m^3), quality/purity (CH_4, H_2S) and energy value of biogas (kWh/m^3)
- Expected VS removal
- Expected digestate quality (TS, pH, pathogen, plant nutrients N, P)
- Control devices applied at the AD site (condense water trap, gas flow meter, pressure gauge, non-corrosive main valve)
- Proposed post-treatment steps for biogas (upgrading, scrubbing, H_2S/H_2O-removal, compressing, bottling)
- Proposed post-treatment steps for digestate (drying, mixing, aerobic composting)?

Checking point: Is there a proven performance record for the proposed technology?
If not: Red flag (i.e. pilot tests are required first)

3.3 Product chain

<u>BIOGAS</u>

- What is the proposed way of biogas distribution (incl. distance from AD plant to biogas user)?
- What is the proposed use of biogas?
- Who are the proposed users of biogas?

<u>DIGESTATE</u>

- What is the proposed way of digestate distribution (incl. distance from AD plant to digestate user)?
- What is the proposed use of digestate?
- Who are the proposed users of digestate?

3.4 Summary of physical system components: Visualized AD system (WHAT?)

- What system components and flows are included in the proposed AD system? Based on the answers given above, the drawing of a process flow diagram is recommended for visualization of the AD chain.

<u>Note</u>: If the proposed AD project under assessment is part of an integrated set of technologies, then these other technologies also need to be included as far as they affect the AD project.

6.2.4 HOW? (Aspects of enabling environments, sustainability)

This fourth dimension is grouped into six main sustainability categories which are first presented hereafter to get a general overview:

- **Technological-operational feasibility criteria**
  - Substrate chain: Organic waste quantity & quality, water, distance to AD plant
  - AD technology: Space and material availability, performance, maintenance strategy, flexibility & robustness
  - Product chain: Biogas quality, digestate quality
- **Environmental feasibility criteria**
  - Use of non-renewable substances
  - Use of chemicals and compounds produced by society
  - Physical degradation and destruction of nature and natural processes
- **Financial-economic feasibility criteria**
  - Funding of AD project
  - Market situation of AD products
  - Analysis of cost-benefit (Net Present Value)
- **Socio-cultural feasibility criteria**
  - Acceptance
  - Willingness to change behaviour
  - Conditions that increase people's capacities to meet their needs
- **Institutional feasibility criteria**
  - Institutional capacity
  - Stakeholder cooperation
- **Policy & legal feasibility criteria**
  - AD policies

In the following section, each question is first presented in the feasibility assessment matrix and then explained afterwards (and some examples given).

4.1 TECHNOLOGICAL-OPERATIONAL FEASIBILITY CRITERIA

4.1.1 Substrate chain

4.1.1	Organic waste quantity	-10	0	+10
a	Amount of **available organic waste** compared to the range needed for sound operation of AD system	*Lacking more than 20% required for sound operation*	*Between 20% less & 20% more*	*Exceeding required amount by more than 20%*
b	Seasonal and periodic (e.g. holidays, festivals, fasting days) **variation in input substrate quantities** compared to the required quantity for sound operation	*Major threat for sound operation*	*Hardly affect the operation*	*Not affect the operation at all*
c	Intended way of **measuring** the daily input quantity	*Not appropriate*	*OK for the moment, needs to be improved*	*Very appropriate*

a. The available amount of biowaste needs to be compared with the quantity required for sound operation (investigated under 6.1.3 What? (3.2). If the question is answered with -10, either dimensioning of digester is too big and needs to be reduced or different additional sources of substrates need to be organized. If answered with 0, the relation between organic waste availability and requirements is OK, if answer +10 is given; sufficient substrate is available for sound operation of the system. But +10 as answer also means that a plan is necessary on how to handle the substrate surplus (to prevent adverse effects on the environment and human health). Depending on the AD system (and the availability of substrate storage), the answering categories can be adjusted (e.g. for 0: between 10% less and 10% more).

b. If the available substrate amount is scarce (i.e. only little higher than the amount required for sound operation) and seasonal or periodic variation is high, the operator of the system is expected to face some problems due to lack of feedstock during certain periods (e.g. in a school during holidays. In such case, it is important that the start-up after holidays is done cautiously to enable adaptation of the microorganisms and avoid acidification due to overfeeding). Answering this question with +10 either means that the variation is negligible or that the events (e.g. fasting days) actually cause a surplus of substrate. In such case, a plan is needed on how to deal with this extra amount of organic waste.

c. This question first aims at detecting if any measurement instrument has been planned at all to guarantee adequate feeding of the AD system and secondly evaluates the suitability of the proposed way of measuring it. 'Not appropriate' would be if no measurement device is planned or if an inappropriate scale (e.g. kitchen scale with a max. weight of 2kg, whereas the required daily feeding load is 200kg) has been chosen. 'OK for the moment' could be if a few persons know how to estimate the weight by volume (e.g. of truck or push cart) but because of high waste variability, the measuring method needs to be improved. 'Very appropriate' could e.g. be a weighting bridge for the collection trucks before emptying their load.

4.1.1	Organic waste quality	-10	0	+10
d	Included waste **separation and pre-treatment** steps compared to required substrate quality	*Not suitable*	*OK for the moment, needs to be improved*	*Very appropriate*
e	Seasonal and periodic (e.g. holidays, festivals, fasting days) **variation in input substrate quality** compared to the required quality for sound operation	*A major threat for sound operation*	*Hardly affect the operation*	*Not affect the operation at all*

d. The proposed separation and pre-treatment steps are compared to the requirements e.g. related to diameter of inlet pipe or TS of digester content (investigated under 6.1.3 What? [3.2], also see 5.2.1). A dry fermentation system e.g. has lower requirements in terms of substrate purity compared to a wet high-tech system where pipes can be clogged or pumps and devices damaged.

e. If the proposed AD technology is sensitive to contamination and thus requires very pure substrate while at the same time the expected seasonal or periodic variation of waste quality is high, the operator of the system might face some problems (during certain periods).

4.1.1	Water	-10	0	+10
f	**Availability & accessibility of water** compared to the required amount (for dilution, pipe flushing, operation in general)	*Not adequate*	*OK for the moment, needs to be improved*	*Adequate*

f. The quantity of water needed for sound operation of the AD system (investigated under 6.1.3) is compared with the availability of water. As a wet fermentation system obviously has much higher water requirements than a dry fermentation system, this question (and also a-f) is very technology-dependent.

4.1.1	Distance from generation to AD plant	-10	0	+10
g	**Distance** from waste generation/transfer station to AD site	*> 10km*	*3 - 10km*	*< 3 km*
h	**Accessibility** of AD plant in terms of geographic & logistic circumstances (road conditions, traffic)	*Poor*	*OK for the moment, needs to be improved*	*Good*

g. Long distance between waste generation or transfer station and AD site is unfavorable as it is connected with additional logistics, higher transportation costs and possibly environmental pollution. The proposed distance criteria are considered to represent appropriate, neutral and inappropriate distances in general. However, the numerical answer categories can be adjusted taking into consideration local circumstances.

h. Accessibility of AD system is considered poor in case of bad road conditions or regular heavy traffic. Bad road conditions also adversely affect the collection vehicles as repairing requirements increase. If concrete plans exist for improvement of the road, the question can be answered with OK. The type and condition of transportation vehicles also need to be taken into consideration when answering this question.

4.1.2 AD Technology

4.1.2	Space availability	-10	0	+10
a	Urban spaces for waste **storage/transfer stations**	*Not available*	*Partly available*	*Completely available*
b	Urban spaces for the **AD system plus working area**	*Not available*	*Partly available*	*Completely available*

a. It is important to have appropriate space available for waste storage or transfer stations to properly sort (or pre-treat) the substrate and to avoid negative effects by environmental pollution or by residents complaining about emitted odors.

b. The availability of space required for the AD system is crucial to start operation. 'Partly available' implies that the provided space is not sufficient in consideration of the (expansion) plans for the near future.

4.1.2	Material availability	-10	0	+10
c	Materials needed for **construction** of the AD system (building materials & equipment)	*Internationally available*	*Nationally available*	*Locally available (< 30km)*
d	Materials needed for **start-up** (inoculation e.g. cow-dung or sludge) of the digester	*Nationally available*	*Regionally available (30-50 km)*	*Locally available (< 30km)*
e	Materials needed for **maintenance & monitoring** (spare parts & equipment)	*Internationally available*	*Nationally available*	*Locally available (< 30km)*
f	Materials needed for the **use of AD products** (e.g. biogas-stove/oven, pipe, generator etc.)	*Internationally available*	*Nationally available*	*Locally available (< 30km)*

c. – f. Locally available materials are preferable due to operational (e.g. availability of spare parts), environmental (e.g. pollution caused by transportation) and financial (e.g. expenses related to organization & transport of material) considerations.

4.1.2	Performance of AD technology	-10	0	+10
g	**Climatic conditions** (mean annual temperature & rainfall, seasonal & day/night variation) for proposed AD technology	*Not suitable*	*Moderately suitable*	*Very suitable*
h	**Process stability** (e.g. prevented risk of acidification) due to the AD-design and/or operation	*Low*	*Moderate*	*High*
i	Expected **process efficiency** (VS-reduction)	*< 50%*	*50 - 70%*	*> 70%*
j	**Designed biogas yield** compared to literature data	*Deviating from literature more than 20% less*	*Deviating from literature within 20% either side*	*Deviating from literature more than 20% more*
k	**Geotechnical conditions** (rock type, risk of erosion/earthquake, groundwater table etc) for the planned AD technology	*Not suitable*	*Moderately suitable*	*Very suitable*
l	Clear **maintenance strategy** (paper listing who has to do what, when and how exactly)	*Not included*	*Partly included*	*All included*
m	Required **essential control devices** (condense water trap, gas flow meter, pressure gauge, non-corrosive main valve)	*Not included*	*Partly included*	*All included*

g. Particularly if the proposed AD technology does not include temperature regulation of digester, then outside temperature is an important influential factor. For underground mesophilic fixed dome system, outside temperature should e.g. not drop lower than 5-10°C throughout the year. As methanogenic bacteria prefer stable environmental condition, it is also important to minimize the temperature change between day and night (e.g. sufficient soil backfilling on underground fixed dome systems). Absence of a temporary roof over a floating dome system where heavy rainfalls are predominant is an example for moderate suitability.

h. A major danger for overall anaerobic conversions is presented when microorganism populations are not balanced. This can be the result of an overload (defined as either an excess of biodegradable organic matter for the active population capable of digesting it), or any circumstances that produce a decrease in active microorganism concentration (abrupt change of temperature, accumulation of toxic substances, flow rate increase etc.). These disturbances mainly affect methanogenic bacteria, whereas the much more tolerant acidogenic bacteria continue to work, producing more acids (= acidification), which in return inhibit the activity of methane-formers. This imbalance can eventually result in a digester failure. Acidification is easier to prevent in two-stage systems due to the possibilities to control the intermediate steps (Mata-Alvarez, 2003). Addition of manure increases the buffer capacity, thereby reducing risk of acidification.

i. Many studies on the anaerobic treatment of biowaste found VS removals in the range of 50–70% with organic loading rates in the range 4–8 kg VS m^3/ day (Vandevivere, De Baere & Verstraete, 2003). Thus process efficiency is considered to be acceptable (neutral) in this range.

j. The expected biogas yield as proposed by the designing company should be compared with literature data (see e.g. Table 12). If the expected biogas yield is substantial lower (e.g. more than 20%) compared to literature (for similar technology and conditions), the reason for this difference needs to be investigated (wrong calculations, estimations, dimensioning?). If much more biogas is produced than expected and used for dimensioning of the digester system, the gas storage volume might be too small, leading to large amounts of biogas escaping (e.g. in the case of fixed dome digesters) and being released to the atmosphere. If on the other hand the expected biogas yield is much higher compared to literature references, it has to be doubted if made promises are realistic.

k. Geotechnical considerations have to be taken into account as they exert a major influence on the outcome of the project. Some examples: If the underground contains hard rock types, construction (digging) might be problematic leading to underground systems not being sufficiently buried (resulting in lack of soil protection and higher temperature deviations between day and night). High water table poses a problem during construction (when dome needs to be dry for making it liquid- and gas-tight) and during operation (if ground water enters digester thus diluting the slurry).

l. A clear maintenance strategy includes an explicit list that states which activities have to be conducted when, how exactly and by whom.

m. Essential control devices include condense water trap (to avoid blockage of gas pipe by condensed water), pressure gauge (to recognize gas loss through leakages [constant low pressure] and escaping e.g. on fixed dome digesters during night time), gas flow meter (to identify drop in gas production due to e.g. acidification or under-feeding) and well-closing, non-corrosive main valve (to enable repairing of gas pipe).

4.1.2	**Flexibility & robustness of AD technology**	***-10***	***0***	***+10***
n	To **changes in feedstock**	*Sensitive*	*Quite adaptable*	*Very adaptable*
o	To **changes in climatic conditions** (temperature & rainfall)	*Sensitive*	*Quite adaptable*	*Very adaptable*
p	To occasional **electricity black-outs** on the AD-operation	*Sensitive*	*Quite adaptable*	*Not sensitive*
q	**Lifespan of digester**	*< 5 years*	*5 - 10 years*	*> 10 years*
r	**Lifespan of most sensitive parts**	*< 1 year*	*1 and 3 years*	*> 3 years*

n. Examples for high flexibility of the AD system to changes in feedstock quantity include smaller size of digester (to ensure that substrate amount is always sufficient) or possibilities of adaptive active digester volume (e.g. fixed dome digesters in series with valves in between). To changes in feedstock quality, a batch-fed dry fermentation system is more adaptable as optimal conditions can be adapted to each batch.

o. Temperature regulation included in an AD system makes the technology less dependent on climatic changes. If no temperature regulation of the digester is included, preheating of substrate could be one option to increase the adaptability of the system. An underground system with sufficient backfilling of soil is considered quite adaptable to climatic changes as it ensures minimal temperature variation.

p. An AD system that requires external energy input through electricity faces serious problems in case of electricity black-outs. If emergency power generator can be guaranteed and organized from an external supplier, the set-up can be considered as 'quite adaptable': If such generator is permanently available on the AD site, the system is 'not sensitive'. Obviously, the system is also 'not sensitive' if the proposed AD technology does not require electricity at all.

q. Based on knowledge and experiences made in other projects, the lifespan of the digester can be stated. The suggested categories need to be adapted depending on the digester type (e.g. tube digesters have a much shorter lifespan compared to fixed dome digesters).

r. It is important to be aware which parts of the AD system are most sensitive and when replacements have to be expected. The designing and constructing companies should know this information and provide it to the persons responsible for operation & maintenance.

4.1.3 Product chain

4.1.3	Biogas quality	*-10*	*0*	*+10*
a	Expected **biogas quality** compared to the required quality (CH_4, H_2S, H_2O content, pressure) for planned biogas utilization purpose	*Not suitable*	*Moderately suitable*	*Very suitable*
b	*Only answer if post-treatment steps included in design:* Designed **post-treatment** steps compared to the planned gas utilization purpose	*Not suitable*	*Moderately suitable*	*Very suitable*
c	**Biogas quality variation** (after post-treatment, if included in design, otherwise just as it comes from digester) for planned biogas utilization purpose	*Very problematic*	*Moderately problematic*	*Not problematic*
d	**Distance** between AD site and biogas utilization site	*> 500 m*	*100 – 500 m*	*< 100 m*

a. The utilization of biogas needs to be in correspondence with the biogas quality (see 5.2.3, Table 10). Even for simple cooking, H_2S should be removed, CH_4 content is of minor importance (if it is above 45% and thus flammable). Condense H_2O however has to be removed through a water trap and pressure needs to be high enough to reach the stove and to burn satisfactory. If biogas is to be used in a CHP system, H_2S and H_sO removal are mandatory. If the produced biogas is intended for the natural gas grid, upgrading of the biogas is additionally required (CO_2 reduction → CH_4 increase).

b. The proposed post-treatment steps are evaluated in terms of their suitability to produce the required quality of the planned biogas utilization (see 5.2.3, Table 10). If no post-treatment steps are included in the design, this question can be skipped.

c. Variations in biogas quality are not considered to be problematic if the gas is used for cooking. If the proposed biogas utilization (e.g. CHP) requires stable biogas composition (e.g. limited H_2S content) and corresponding post-treatment steps are integrated, the biogas quality variation is 'not problematic'.

d. The distance between AD digester and location of biogas utilization should be chosen as short and direct as possible. With long distances, the following risks are increased: damage of the gas pipe resulting in gas leakages, wrong positioning of condense water traps, and pressure loss. In addition, very long transport of biogas requires additional technical and logistic efforts (upgrading, bottling, transporting).

4.1.2	Digestate quality for planned utilization	*-10*	*0*	*+10*
e	**Digestate quality** compared to the required quality (texture, pH, NPK-, pathogen-, heavy metal content) for digestate use	*Not suitable*	*Moderately suitable*	*Very suitable*
f	*Only answer if post-treatment steps included in design:* Designed **post-treatment** steps compared to the planned digestate utilization purpose	*Not suitable*	*Partly suitable*	*Very suitable*
g	**Quality variation** (with post-treatment, if included in design, otherwise just as coming from digester) for planned use of digestate	*Very problematic*	*Moderately problematic*	*Not problematic*
h	**Distance** between AD site and digestate utilization site	*>50 km*	*20-50 km*	*< 20 km*

e. The utilization of digestate needs to be in correspondence with the digestate quality. Thus it is important to investigate and compare the requirements for the digestate with the expected quality of it.

f. The proposed post-treatment steps are evaluated in terms of their suitability to produce the required quality of the planned digestate utilization. If no post-treatment steps are included in the design, this question can be skipped.

g. Variations in digestate quality are only considered to be problematic if the digestate does not undergo any post-treatment and the planned utilization requires stable quality.

h. The longer the distance between AD digester and location of digestate utilization, the higher the costs (of transportation) and possibly also the environmental pollution.

4.2 ENVIRONMENTAL FEASIBILITY CRITERIA

4.2.1 Use of non-renewable substances extracted from the Earth's crust

4.2.1	Use of non-renewable substances extracted from the Earth's crust	*-10*	*0*	*+10*
a	Use of **non-renewable materials in collection & transport** of the AD substrate (substrate chain component) leading to increased concentration in any of the environmental compartments (water, soil, air)	*More than in current system*	*Similar to current system*	*Less than in current system*
b	Use of **non-renewable materials in construction and operation** (AD technology chain component) of AD technology leading to increased concentration in any of the environmental compartments (water, soil, air)	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
c	Use of **non-renewable materials in distribution/transport and utilization** of the AD products (biogas/digestate, substrate chain component) leading to increased concentration in any of the environmental compartments (water, soil, air)	*Not acceptable*	*Moderately acceptable*	*Very acceptable*

a. The use of non-renewable materials in collection and transport (e.g. fossil fuels, metals) of the proposed AD system is compared to the current system.

b. The use of non-renewable materials in construction & operation (e.g. fossil fuel, metals) is considered very acceptable if it does not lead to increased concentration/contamination in any of the environmental compartments (water, soil, air). Moderately acceptable implies that there is small unavoidable contamination.

c. The use of non-renewable materials in distribution, transport and utilization (e.g. fossil fuel, metals) is considered very acceptable if it does not lead to increased concentration and contamination in any of the environmental compartments (water, soil, air).

4.2.2 Use of chemicals and compounds produced by society

4.2.2	Use of chemicals and compounds produced by society	*-10*	*0*	*+10*
a	Use of **chemicals/compounds** produced by society in **collection & transport** of the AD substrate leading to increased concentration in any of the environmental compartments (water, soil, air)	*More than in current system*	*Similar to current system*	*Less than in current system*
b	Use of **chemicals/compounds** produced by society in **construction and operation** of AD technology leading to increased concentration in any of the environmental compartments (water, soil, air)	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
c	Use of **chemicals/compounds** produced by society in **distribution/transport and utilization** of the AD products (biogas/digestate) leading to increased concentration in any of the environmental compartments (water, soil, air)	*Not acceptable*	*Moderately acceptable*	*Very acceptable*

a. The use of chemicals and compounds produced by society (e.g. toxic compounds like DDT, dioxins) in collection and transport is compared to the current system.

b. The use of chemicals and compounds produced by society (e.g. toxic compounds like DDT, dioxins, AD products) in construction and operation is considered very acceptable if it does not lead to increased concentration and contamination in any of the environmental compartments (water, soil, air). Moderately acceptable implies that there is only contamination to a small degree.

c. The use of chemicals and compounds produced by society (e.g. toxic compounds like DDT, dioxins, AD products) in distribution, transport and utilization is considered very acceptable if it does not lead to increased concentration and contamination in any of the environmental compartments (water, soil, air).

4.2.3 Physical degradation and destruction of nature and natural processes

4.2.3	Physical degradation and destruction of nature and natural processes	*-10*	*0*	*+10*
a	**Physical degradation and destruction** of nature and natural processes as a result of the AD technology (e.g. siting)	*Not acceptable*	*Moderately acceptable*	*Very acceptable*

a. 'Not acceptable' means if there is clear physical degradation and destruction of nature and natural processes (e.g. over-harvesting of forests, paving over critical wildlife habitats) as a result of the AD project. 'Moderately acceptable' signifies unavoidable disturbances of nature to only a small degree.

4.3 FINANCIAL-ECONOMIC FEASIBILITY CRITERIA

4.3.1		*-10*	*0*	*+10*
a	**Funding** situation	*Disruptive*	*Neutral*	*Supportive*
b	**Market** situation	*Disruptive*	*Neutral*	*Supportive*
c	**Cost-benefit** analysis (**Net Present Value,** NPV)	*Costs Higher (NPV < 0)*	*Costs covered, no profit (NPV = 0)*	*Benefits Higher (NPV > 0)*

a. Funding of AD project

Descriptive question

How is the AD project funded? If it is based on a loan, how are the conditions including payback period and interest rate? Are there financial incentives by local or regional authorities? Which roles do Clean Development Mechanism (CDM) or Payment for Environmental Service (PES) play?

Qualitative question

How is this funding situation considered to be?

- Supportive: low interest rate (< 2%), favorable return period (start, flexibility, space for failure), incentives like exclusive right of access to waste etc.
- Neutral condition: Neither supportive nor disruptive
- Disruptive: Discouraging licensing procedure, high interest rate (> 5%), unfavorable return period (immediate start, short period, no flexibility) etc.

b. Market situation

Descriptive question

(A comprehensive market analysis includes location, attitudes & perceptions, uses, quantity, quality, ability to pay, willingness to pay, purchasing behavior and estimated potential. As some of these issues are treated in other feasibility categories, the main focus here is):

How is the profile of the targeted customer for biogas & digestate? How are their demand, willingness and ability to pay for the products? Which factors (e.g. competitors) influence the sales of the AD products? Description of the 4 P's of marketing (product, price, place, promotion) for the AD products.

Qualitative question

How is this market situation considered to be?

- Supportive: High interest and demand, clear plan for improvement of marketing, dis-satisfaction with current situation or alternative products etc.
- Neutral: Neither supportive nor disruptive
- Disruptive: Unhealthy product, high price of product, incontinuous supply, lack of pro-motion activities, unsuitable placement of business etc.

c. Analysis of cost-benefit (Net Present Value)

The broad purpose of CBA is to help rational decision making. It is most useful for deciding whether re-sources should be allocated to a particular project that is under assessment. For a project with costs or benefits that accrue over extended periods (years), a way is needed to aggregate the benefits and costs that arise in different years. In CBA, future benefits and costs are discounted relative to present benefits and costs in order to obtain their present values (NPV). For this thesis work, only certain elements of CBA have been used.

Overall question

Is the proposed AD project a business case i.e. is the revenue every year sufficient to pay all the costs?
Is the implementation of the proposed AD project financially more attractive than the current situation?
Note: If AD technology is part of an integrated project with other products than biogas and digestate other products also need to be included in the financial-economic analyses.

What are the costs of the AD project?

- Re-payment of loan
- Investment costs: Technical costs related to planning, construction, land use, operation (collection, transport to AD plant, pre- treatment, water for dilution, operation, post-treatment of AD products, transport to user of AD products), maintenance (monitoring, re placements etc.)
- Operational costs: Transaction costs related to operation (salaries, trainings, administration, promotion
- Other costs: Taxes

What are the revenues from the AD project?

- From biogas: in firewood equivalent (or any other fuel used locally for the same purpose)
- From digestate: in fertilizer equivalent (e.g. cow dung, artificial fertilizer)
- Savings of other costs (transport to disposal site, costs of disposal fee, if any)

Net Present Value

To account for the time value of money, the obtained values from the financial assessment (cost-benefit-analysis) are used to calculate the net present value (NPV).

Checking point: If funding or market situation is disruptive, costs higher than benefits (NPV < 0) → Red flag

4.4 SOCIO-CULTURAL FEASIBILITY CRITERIA

4.4.1 Acceptance

4.4.1	Acceptance	-10	0	+10
a	Attitude towards handling **AD substrates** (as required for the proposed AD chain) in relation to local ethics/culture	*Mainly negative*	*Neutral*	*Mainly positive*
b	Attitude towards **AD technologies** (process, side-effects) in relation to local ethics/culture	*Mainly negative*	*Neutral*	*Mainly positive*
c	Attitude towards **AD products** (handling, safety of application) in relation to local ethics/culture	*Mainly negative*	*Neutral*	*Mainly positive*

a. This question pertains to handling of organic wastes and if the attitude (deeply rooted in culture) towards touching, sorting and transporting waste is perceived negative, neutral or positive.

b. How is the attitude towards AD technologies and its real or perceived side-effects like odor, noise, visual disturbances in correspondence to local ethics and culture?

c. Are the AD products (handling of biogas & digestate, safety) perceived as negative, neutral or positive?

4.4.2 Willingness

4.4.2	Willingness	*-10*	*0*	*+10*
a	Willingness to change behavior in terms of **source separation** (if required in AD project)	*Low*	*Medium*	*High*
b	Willingness to change behavior (if required) in terms of using **biogas for cooking or planned purposes**	*Low*	*Medium*	*High*
c	Willingness to change behavior (if required) in terms of using **digestate as fertilizer**	*Low*	*Medium*	*High*

The behavior (or habits) under discussion can be learned and changed more easily compared to attitude assessed under 4.4.1

Only answer questions a.- c. if change of behavior is required for proposed project

a. How is the willingness of the waste generators to separate the organic fraction of their waste? Make use of results from previous waste projects, surveys with similar focus or expert opinions.

b. How is the willingness of the customers to use biogas for cooking? Make use of results from previous AD projects, surveys with similar focus or expert opinions.

c. How is the willingness of the customers to use digestate as fertilizer? Make use of results from previous AD or composting projects, surveys with similar focus or expert opinions.

4.4.3 Conditions that increase people's capacities to meet their needs

4.4.3	Increase of people's capacities	*-10*	*0*	*+10*
a	Conditions created by AD project in terms of **employment generation**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
b	Conditions created by AD project in terms of paying **fair salaries**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
c	Conditions created by AD project in terms of creating **safe working conditions**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
d	Conditions created by AD project in terms of **equal opportunity of inclusion**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
e	Conditions created by AD project in terms of opportunity for **poverty reduction**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*
f	Conditions created by AD project in terms of **distribution of burden & benefits (economic, social, environmental)**	*Not acceptable*	*Moderately acceptable*	*Very acceptable*

Does the AD project create conditions that undermine people's capacities to meet their needs in terms of:

a. Employment generation: Creation of new jobs as a result of AD project (not acceptable: situation will worsen compared to current sate; moderately acceptable: hardly any change; very acceptable: AD project will create more jobs compared to the current situation)

b. Fair salaries: Compared to other jobs and considering the workload and exposure to hazardous substances.

c. Safe working conditions: Protection clothes, health insurance, emergency kits available, proper instruction about health risks and how to avoid exposure.

d. Equal opportunity of inclusion: Independent of gender, tribes, and minority groups. Do members of the informal sector have an equal chance for participation?

e. Poverty reduction: Does the AD project lead towards reducing the gap between poor and rich?

f. Distribution of burden and benefits: Are the economic (e.g. reduced expenses for cooking), social (e.g. reduced health risks due to reduced smoke exposure from indoor cooking with firewood) and environmental (e.g. less drinking water pollution due to improved waste collection) benefits equally distributed or does only a small group of people benefit from the AD project? Likewise, how is the burden resulting from the project (e.g. higher waste collection fees, negative effects for AD site residents) distributed?

4.5 INSTITUTIONAL FEASIBILITY CRITERIA

4.5.1 Institutional capacity

4.5.1	Institutional capacity	*-10*	*0*	*+10*
a	Local capacity to **design, supply materials, build and operate** AD plant and make proper use of AD products	*Not available*	*Partly available*	*Completely available*
b	Local, regional or national capacity to provide **training & education** for sound construction, operation & maintenance of AD plant and proper use of AD products	*Not available*	*Partly available*	*Completely available*
c	Local capacity to carry out **process monitoring and trouble-shooting** within the AD-chain	*Not available*	*Partly available*	*Completely available*
d	**Physical spaces for education, training and workshops**	*Not available*	*Partly available*	*Completely available*

Institutional capacity includes skills, knowledge and attitudes of staff in organizations involved, enabling environment in which they function, possibility for continuous learning, physical capacity&room to do the activities.

a. Is the capacity needed for designing, building and operating the AD system locally (within 30 km of the AD site) available? If this capacity is available by a stakeholder who is not actively involved or who is not willing to participate in the AD project, the question has to be answered with 'not available' (same for b and c)

b. Is the capacity needed for providing trainings (construction, operation and maintenance of the AD system) at least nationally available?

c. Is the capacity for process-monitoring and trouble-shooting locally (within 30 km of the AD site) available?

d. Is there sufficient space do conduct trainings and workshops?

4.5.2 Stakeholder cooperation

4.5.2	Stakeholder cooperation	*-10*	*0*	*+10*
a	**Cooperation** within whole AD chain	*Non-existent*	*OK for the moment but can be improved*	*Well established*
b	**Clarity of responsibilities** for relevant stakeholders within the AD chain	*Non-existent*	*OK for the moment but can be improved*	*Well established*
c	**Possibilities to motivate** stakeholders within the AD chain to participate & take their responsibility	*Non-existent*	*OK for the moment but can be improved*	*Well established*

a. How is the cooperation within the chain as proposed by the AD project considered to be? Are stakeholders already used to collaborate or are they willing to do so?

b. Does each stakeholder in the AD chain know its responsibilities (which tasks to do when, how and how to inform about encountered problems)? Is there one stakeholder who has the overview over the complete AD chain and who is in charge of controlling smooth operation?

c. Do the stakeholders in the chain have (e.g. financial) benefits in contributing to sound operation of the AD process? Are they aware of these benefits?

4.6 POLICY & LEGAL FEASIBILITY CRITERIA

4.6.1 AD policies

4.6.1	AD policies	-10	0	+10
a	**Current** (nat. & intern.) **policies** regarding AD	*Disruptive*	*Neutral*	*Supportive*
b	**Current** (nat. & intern.) **legislation, standards and regulations** relevant for AD	*Disruptive*	*Neutral*	*Supportive*
c	**Current law enforcement practices**	*Low*	*Medium*	*High*
d	**Prospect** of establishing **supportive policies** regarding AD	*Low*	*Medium*	*High*
e	**Prospect** of enacting and enforce **supportive legislation, standards and regulations** relevant for AD	*Low*	*Medium*	*High*

a. Are the current national and international policies disruptive, neutral or supportive regarding the proposed AD project?

b. Are the current national and international laws, standards and regulations that are relevant for AD disruptive, neutral or supportive?

c. Are current enforcement practices of laws, standards & regulations disruptive for the AD project (e.g. high enforcement for very strict laws/standards), neutral (e.g. medium enforcement for medium strict laws/standards) or supportive (e.g. low enforcement for strict laws/standards)?

d. Are the chances that supportive policies for AD will be established in the near future low, medium or high?

e. Are the chances that supportive legislation, standards and regulations relevant for AD will be enacted and enforced in the near future low, medium or high?

Checking point: Any question answered in this part of the tool (How?) that received an answer in the -10 category needs to be carefully checked to assess if this could be a potential project breaker

4.7 UNCERTAINTY FACTORS

Due to the risk that things develop differently than expected and that data, assumptions, estimations and information used for the feasibility assessment are not correct or unreliable, uncertainty factors are incorporated. This is done by means of an additional list of questions grouped according to the six feasibility categories. The same person who conducted the feasibility assessment so far will answer these questions, but it is very likely that other stakeholders need to be contacted and questioned to get the necessary information.

4.7.1	Technological-operational uncertainties	*Factor *0.5*	*Factor *1*
a	Risk that required quantity and quality of **substrate** will not be delivered (due to whatever reasons)	*High*	*Low*
b	Risk that required quantity and quality of **water** will not be delivered (due to whatever reasons)	*High*	*Low*
c	Risk that required **material** for construction, operation & maintenance will not be delivered	*High*	*Low*
d	Risk that AD technology will not **perform** as designed in terms of product quality	*High*	*Low*
e	Risk that **maintenance** will not be done	*High*	*Low*
f	Risk that chosen **location** of the AD system will not be suitable in the future (e.g. cut-off roads)	*High*	*Low*
g	Risk that assessment of technical-operational feasibility is **not reliable** (lack of data, wrong calculation, inadequate estimations)	*High*	*Low*

4.7.2	Environmental uncertainties	**0.5*	**1*
a	Risk that assessment of environmental feasibility is **not reliable** (lack of data, inadequate estimations)	*High*	*Low*

4.7.3	**Financial-economic uncertainties**	**0.5*	**1*
a	Risk that **loans for investment** will not be received	*High*	*Low*
b	Risk that **actual cost of construction** will be substantially higher than planned (thereby endangering completion of construction)	*High*	*Low*
c	Risk that **actual cost of operation** will be substantially higher than planned (thereby endangering sound operation)	*High*	*Low*
d	Risk that **demand for biogas** will decrease substantially in the future	*High*	*Low*
e	Risk that **demand for digestate** will decrease substantially in the future	*High*	*Low*
f	Risk that **customers will refuse to buy** the AD products	*High*	*Low*
g	Risk that the distribution channel for AD products will not function or cease to exist	*High*	*Low*
h	Risk that assessment of financial-economic feasibility is **not reliable** (lack of data, wrong calculation, inadequate estimations)	*High*	*Low*

4.7.4	**Socio-cultural uncertainties**	**0.5*	**1*
a	Risk that **acceptance** of AD technology and its products will substantially worsen	*High*	*Low*
b	Risk that required **behaviour** will not be attained	*High*	*Low*
c	Risk that **conditions created by AD** (in terms of employment generation, paying fair salaries, creating safe working conditions, equal opportunity of inclusion, opportunity for poverty reduction, distribution of burden & benefits) will not be achieved or actually result in the contrary	*High*	*Low*
d	Risk that assessment of socio-cultural feasibility is **not reliable** (lack of data, inadequate estimations, incorrect assumptions)	*High*	*Low*

4.7.5	**Institutional uncertainties**	**0.5*	**1*
a	Risk that **institutional capacities** will worsen in the future so as to jeopardize a well functioning AD chain	*High*	*Low*
b	Risk that **stakeholder cooperation** will worsen in the future so as to jeopardize a well functioning AD chain	*High*	*Low*
c	Risk that assessment of institutional feasibility is **not reliable** (lack of data, inadequate estimations, incorrect assumptions)	*High*	*Low*

4.7.6	**Policy & legal uncertainties**	**0.5*	**1*
a	Risk that **disruptive policies** regarding AD will be established	*High*	*Low*
b	Risk that **disruptive legislation, standards and regulations** relevant for AD will be enacted and enforced	*High*	*Low*
c	Risk that assessment of policy & legal feasibility is **not reliable** (lack of data, inadequate estimations, incorrect assumptions)	*High*	*Low*

6.3 Instructions for use of feasibility assessment tool (Excel)

In order to facilitate the performance of this feasibility assessment, a working document in the form of an Excel sheet has been prepared (Appendix VII & VIII). The Excel tool contains five sheets:

1. WHY
2. WHO
3. WHAT
4. HOW
5. Results

These sheets have to be worked through successively. The cells that need to be filled out are surrounded by a dotted frame. Some of these dotted cells contain a *drop-down* function, i.e. that a grey arrow appears on the right side of the cell (when clicking on the cell). Clicking on the arrow results in dropping down of a list of possible answers, in most cases it is an 'x' to insert if this cell answers the question most accurately (an 'x' can also be manually inserted by using the computer keypad). A red small triangle on the upper right corner of a cell indicates a hidden comment that can be made apparent by positioning the cursor on this cell or by clicking on it.

The practical procedure for applying the feasibility assessment tool is according to the following steps (keeping in mind that the developed assessment tool needs to be fine-tuned for each context in order to suit the specific circumstances in which it is applied):

I. A stakeholder with certain AD in-depth knowledge (expert) descriptively answers the questions pertaining to first three dimensions (WHY, WHO, WHAT). In order to do so, the expert contacts the different stakeholders for gathering information about the local AD context.
II. The expert answers the questions of the fourth dimension (HOW) by marking the most suitable answer of the three pre-given categories (also requires collaboration with stakeholders).
III. The expert fills out the questionnaire about the uncertainty factors by marking the most suitable answer of the two pre-given categories (again, this might require collaboration with stakeholders).
IV. The expert organizes a platform to ask stakeholders to assign weights between 1 and 10 to each of the main feasibility category (1: not important for success to AD project; 10: essentially important for success of AD project). This can be done with each stakeholder individually or even more recommended is to do it as part of a multi-stakeholder workshop so as to enable clarifications and discussions.

The Excel sheets 4 (HOW) and 5 (Results) then perform the following steps for assessing the feasibility of the AD project:

- The average of scores from each feasibility category is calculated based on the individual scores given by the expert (in collaboration with stakeholders). This procedure results in a value between -10 and +10 for each category. The cell colour of each average sub-criteria score changes according to its result (< 0: red; = 0: yellow; > 0: green).
- Each mean score of a feasibility category is multiplied with the weight assigned by a stakeholder (between 1 and 10), which results in a weighted score (number in the range of -100 and +100).
- Each main feasibility category also includes questions for assessing the uncertainty. Answering a question with high uncertainty is translated into a factor 0.5, whereas low uncertainty translates into a factor 1. As explanation, if a weighted score is multiplied by an uncertainty factor of 1 implies that the weighted score does not change, whereas a multiplication with a factor 0.5 (high uncertainty) results in an uncertainty deviation from the weighted score. The average factor per feasibility group is used.

In Excel sheet 5 (Results), two different types of visualization figures are generated. The first one presents the overall feasibility of the AD project (scores were multiplied by mean weights from stakeholders), the second one reveals the differences in stakeholders' perspectives. These visualization figures can serve as a basis for discussion that hopefully leads to improvement of the proposed projects.

7 Application of feasibility assessment tool in Bahir Dar

7.1 WHY? (Drivers and motivations in Bahir Dar)

Dream Light was one of the actors in the development of the ISWM Plan initiated by FfE and UNEP. Discussions within the ISWM stakeholder workshops led to recommendations to start a project for recycling of organic waste in Bahir Dar in an integrated manner. 'Integrated' implies that the project encompasses a portfolio of different technologies for valorisation of organic waste, generating a variety of products: Biogas, compost and charcoal briquettes (see 4.2.6 for more details about the technologies).
Based on these recommendations of the ISWM Plan, Dream Light approached UNDP for financial and ThiGro Power for technical support in this project.

When inquiring about Dream Light's main driving force behind this integrated organic waste project, Alemnew (2011) clearly stated: While environmental and health concerns were the initial reasons for the establishment of Dream Light and its waste collection services in 2008, financial aspects are now the main drivers for this organic recycling project. He further explained that it is crucial for the company's survival and growth to generate sufficient revenues and one of the options is to valorize parts of the collected waste. It was already Dream Light's strategy from the beginning to first give emphasis to human and environmental health by offering proper waste collections services and then in the second stage to shift the focus on recycling activities to increase the revenues (without reducing the efficiency of the collection services). The full name under which Dream Light is registered underlines this planned sequence of priorities: Dream Light Solid Waste Cleaning and Recycling PLC. Or as Alemnew (2011) put it: "*It is important that we not only clean the city, but also do recycling to make it a business.*" There was no pressure exerted by the municipality or by the public for these recycling activities.
Alemnew (2011) stated that Dream Light recognizes the urge to upgrade the disposal site for reducing the risk to health of the site-residents and of the environment. However, this is the responsibility of the EPA and the municipality and is not within the scope of Dream Light's possibilities. Dream Light sees the proposed recycling activities as a contribution for (organic) waste reduction leading to less waste being disposed on the open dumpsite.
The first stage of the Organic Recycling Centre as described in 4.2.6 is seen as a prototype project to gain experiences that can be up-scaled later on. Dream Light does not expect to make much profit from this first stage but aims at reaching a zero-profit level. It is considered to be more important to get the relevant stakeholders actively involved, convince them of the benefits of the project and gain their support for the next expansion stage (Alemnew, 2011).

The main interest of the municipality is to have a clean city for tourists and citizens of Bahir Dar. It thus appreciates Dream Light's collection efforts and hopes for the success of the recycling project as it will enhance the city's reputation (Getahun, 2011). The City Administration showed its support by providing cheap land for Dream Light's Organic Recycling Centre. While the municipality considers its general attitude towards Dream Light's recycling activities to be supportive, Dream Light regards it as neutral (Getahun, 2011; Alemnew, 2011). Dream Light argues that the municipality does not play a very active role in the project and sees the demonstration of benefits as one of the project's goals of DL. Dream Light hopes that this will lead to more engagement of the municipality in the up-scaling stage of the project.

UNDP provided a loan of 1.6 Mio ETB with an interest rate of 10% and a payback period of 4 years. The money has been given as a grant to City Administration and has to be paid back to the CA by Dream Light.
The main driving force and focus of UNDP is not solid waste management per se, but successful private-public partnerships which lead to good, fast and effective development. Their current focus is specifically on development activities (packages) that lead to improved protection of the environment. As one of the 'growth development packages' is solid waste management, Dream Lights project fits well into UNDP's scheme. Thus it was rather easy to convince UNDP to support DL's recycling project (Alemnew, 2011).

While tourism is seen as one major indirect driving force for Dream Light's activities in general and the recycling project in specific (to gain the support of the City Administration), other driving forces such as academic interest are important to consider and include, but it was not considered to be a main initial motivations for the project.

7.2 WHO? (Stakeholders in AD system in Bahir Dar)

A provisional list of stakeholders was created and afterwards complemented with additional actors mentioned by the interviewed persons (Alemnew, DL; Fenzie, BoEPLAU; Getahun, CA; Kada, SNV). The analysis of stakeholders (as presented in Table 15) was developed in collaboration with Alemnew (Dream Light). When going through the stakeholder analysis, the AD part of the integrated ORC was focused on.

Table 15: Overview of stakeholders in AD project of Bahir Dar

Stakeholder	Role	Power	Interest	Individual drivers	Means of intervention
Dream Light	Initiator, operator	High (9)	Supportive (10)	Revenue, gain support for future projects	Operation & maintenance, main responsibility
ThiGro Power	Contractor	High (9)	Supportive (10)	Successful operation	Technical skills & training
UNDP (before start)	Funding party, promoter	High (10)	Supportive (9)	Successful showcase (PPP), development, creating employment	Finance Promotion
City Administration	Land owner, responsible for SWM	High (10)	Neutral (5)	Reduce waste Clean, attractive city	Land, allows collection service
BoEPLAU	Controller, evaluator	High (10)	Neutral (6)	Rules & regulations to be followed	Rules & regulation (veto if EIA neg)
Bahir Dar University	Scientific supporter	Medium (5)	Supportive (8)	Research opportunities for students	Scientific resources (knowledge, lab, students)
Bureau of Health	Controller, protector	Medium (7)	Neutral (5)	Protect health of community & workers	Policies for control, tests
Reg. Gov't	Decision maker about land, finance issues	Medium (5)	Neutral (6)	Create jobs, clean city	Laws & regulations
Reg. Agency Energy&Mines	Lead organization of SNV proramme at reg. level	Medium (5)	Neutral (5)	Good AD reputation. No direct involv. in BD project	Policy formulation, Promotion of renewable energy
Waste generators	Substrate providers	Medium (5)	Neutral (4)	Have clean living & working area	Provide waste, refuse to pay
SNV	AD advisor (focus on domestic AD)	Low (2)	Supportive (9)	Pos. image of BG, future focus on urban BG	Technical knowhow, AD network
GIZ	User of briquettes	Low (2)	Supportive (5)	Future biogas projects (?), now focus on briquettes	Relation to Reg. E&M Agency
UNDP (now)	Funder Promoter	Low (2)	Supportive (9)	Successful showcase (PPP), development, creating employment	Finance, promotion
LEM Ethiopia	NGO active in AD and SWM	Low (1)	Supportive (7)	Successful AD projects, good reputation for biogas	Promotion
Site residents	User of products, Affected by technology	Low (1)	Neutral (5)	Cheap/good bread No neg. effects	Complaints to police, CA and Reg. govt
Ministry of Agriculture/ARARI	Tester & promoter of digestate use	Low (1)	Neutral (8)	Good quality fertilizer	Testing quality on experimental field
Informal recyclers	Colecting, trading, selling recyclables	Low (2)	Neutral (4)	Making business	Trading for low prices
Bakeries	Competitors	Low (1)	Disruptive (2)	Max. profit, increase capacity, less competition	Bad reputation of AD-bread

The numbers in brackets in the column *power* and *interest* can be explained as follows: Alemnew was initially asked to rate the *power* and *interest* of each stakeholder with a score in the range 1 – 10 (where 1 means low and 10 means high power/interest). At a later stage, it was realized that rather than finding out the level of interest, it is important to examine if the stakeholders' interest is supportive, neutral or even disruptive towards the AD project. Thus the answer categories were adjusted to low, medium, high

(*power*) and disruptive, neutral, supportive (*interest*) and in a second round, Alemnew was asked to do the power/interest evaluation of stakeholders once again using the new answer categories.
Figure 43 presents the power-interest Matrix of the stakeholders in the AD project in Bahir Dar. A more detailed analysis of how much *interest* and *power* each stakeholder has in/towards one of the three specific parts of the AD chain (substrate chain, AD technology, product chain) can be found in Appendix IX.

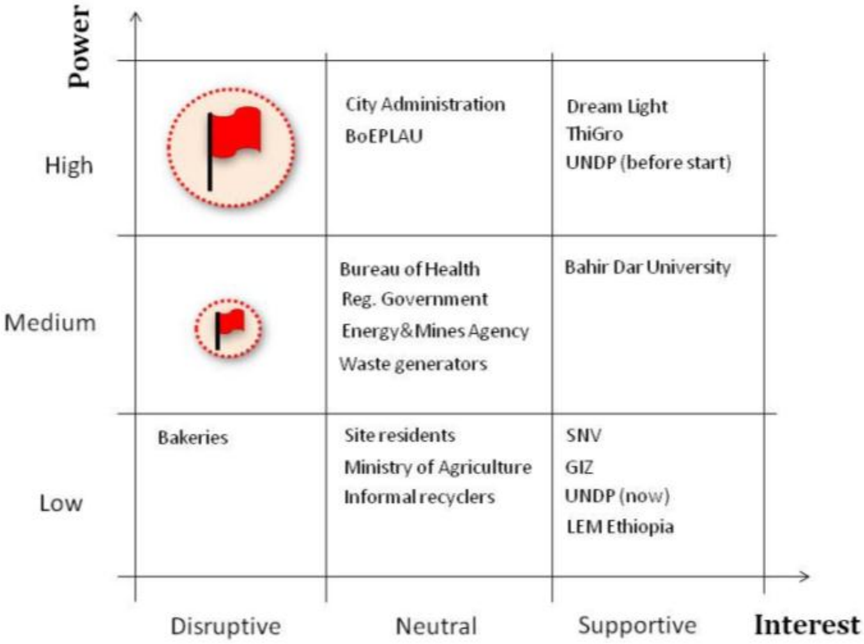


Figure 43: Power-interest Matrix of stakeholders in AD project of Bahir Dar

Regular meetings of the AD stakeholders are not planned. However, most stakeholders would appreciate a platform for regular discussions. Dream Light proposes to hand over the responsibility for such meetings to Bahir Dar University. BDU is considered as the right party to take the lead due to their capacity (AD knowledge, availability of meeting rooms and technical infrastructure). In addition, it would be in accordance to their intention to establish BDU as a Centre of Excellency for Renewable Energy.

7.3 WHAT? (Physical components & flows of AD chain in Bahir Dar)

SUBSTRATE CHAIN

- Substrate requirements

According to ThiGro Power (Dejene, 2011), the required substrate quantities for the integrated organic recycling centre in the beginning are:
Briquetting factory: 950 kg/day
AD system (62 m^3): 650-700 kg/day
Composting pit (150m^3): 450 kg/day

The exact type of organic waste for each technology has not been specified. The only information by ThiGro Power and Dream Light was that for briquetting production, rice husks are tested in the beginning and later on dry organic agricultural wastes will be used. The proposed substrate for the AD system was generally described as wet biowaste (e.g. vegetable and fruit waste), whereas for composting, dry biowaste (e.g. garden waste) will be used. It is assumed that the average TS content of biowaste in Bahir Dar is 25% and VS content is 90% (Dejene, 2011). In the future, it is considered to also insert slaughter house waste from the nearby abattoir into the biogas digester. However, contradictory statements were made related to this issue (Alemnew, 2011; Dejene, 2011). At the end, it was concluded that the start-up and first period of feeding will be done with biowaste (VFY-waste) only.

In terms of seasonal variation, the changes in organic waste quantity and quality are expected to be minimal, as the Ethiopian diet throughout the year is not subject to major changes. After some of the religious festivals, a small increase in (organic) waste is expected due to the special meals prepared for these celebrations (Alemnew, 2011).

- <u>Collection and transportation</u>

As there is currently no waste segregation at source practiced in Bahir Dar and transfer stations are neither designed, nor designated, the waste will in the near future still be collected unsegregated and by passing through the unofficial collection points. In the first stage of the project operation, Dream Light intents to only use organic waste collected in the morning from commercial areas (market, hotel, restaurants, juice centers) as substrate for the recycling centre. These commercials are mostly located in Gish Abay and Sefene Selam kebele. The drivers of the DL collection trucks, controllers and workers will be informed to pre-separate suitable waste streams. Focusing on waste from these sources will facilitate separation at the sorting station which is located on the recycling site. It is intended to only bring the required daily amount of organic waste to the recycling site otherwise storage facilities would be required and the risk of unpleasant odor emissions might increase. In the beginning, organic waste from residential areas is not in the focus, but at a later stage (when segregation in different bags at household level is practiced) wastes from households will also be used (Alemnew, 2011). The means of collection and transportation as well as the staff available for waste collection stay the same than in the current system (described under 4.2.3).

AD TECHNOLOGY

As described in 4.2.6 the AD-system is part of the 'Integrated Organic Recycling Site' which consists of an AD-plant, composting pit and bio-briquetting factory.

- <u>Location</u>

The AD system is located about 3 km in the south of Bahir Dar City, at the left side of Bahir Dar – Tis Abay main road (very bumpy) between municipality slaughter house and ANRS special police force camp. The open dumpsite 'Gordma' is situated 1 km further on this road on the right side. The whole 'Integrated Organic Recycling Site' comprises an area of 10'000 m^2, which is rented from the City Administration for 0.5 ETB/m^2/y. The site has water supply but no accurate electricity connection yet (3-phase-line needs to be transformed into 4-phase line).

- <u>Design</u>

The proposed AD technology is an underground fixed-dome system, SINIDU-model with a total volume of 62 m^3, a gas storage volume of 13 m^3 and an active volume 49 m^3 (see design plan in Figure 44).

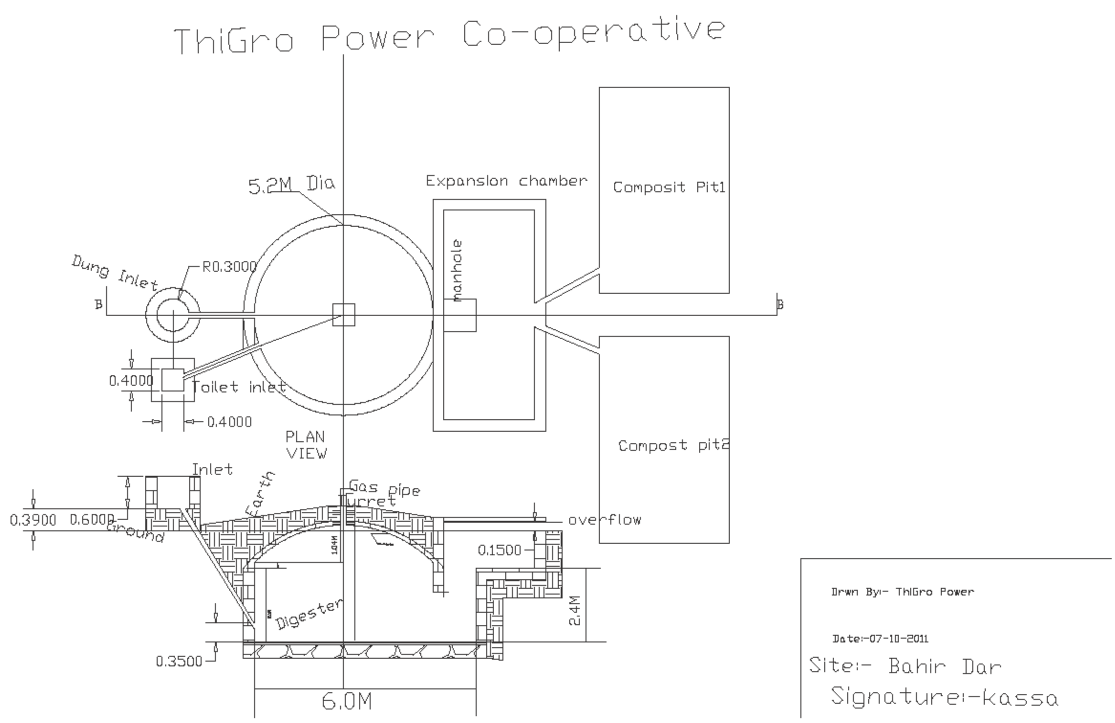


Figure 44: Design plan of AD system (62 m^3) by ThiGro Power

The walls are built with bricks. To ensure gas tightness, a mix of honey combs and engine oil is applied on the inside of the gas storage dome. According to Dejene (2011), the operating parameters are:

- PH = 7.5
- Temperature 30-40^{o}c
- C/N Ratio = 25-33
- Daily feeding load: 650-700 kg wet weight/day
- SRT and HRT = 30 days

- Pre-treatment and feeding

Inorganic materials (e.g. metals, plastic, glass, bones) need to be removed from the daily amount of 650-700 kg of required organic waste for the AD system. In order to reach a TS content of approximately 10% in the digester, the substrate (estimated TS of about 25%) needs to be diluted in a 1:2.5 ratio. This means that a daily quantity of 1'625-1'750 Liters is required for dilution (Dejene, 2011). Bulky substrate pieces of the sorted substrate will be chopped manually before it enters the inlet pipe (ø 20 cm) of the digester.

PRODUCT CHAIN

- Biogas

According to ThiGro Power (Dejene, 2011) the expected gas yield is 12m^3 biogas/day, of which 8m^3 (68%) is methane, 3.6m^3 (30%) CO_2 and the remaining 2% are trace gases. The energy content will be 72kWh per day (12m^3 * 6kWh/m^3) for heating of the bread oven. Condense water traps are planned to be installed every 30 meters at the lowest points. A pressure gauge (up to 20mbar) will be connected to the gas pipe (Dejene, 2011). The biogas will be de-sulphurized by means of a H_2S-filter (container filled with iron chips). The biogas will be used for baking bread, 500 breads per day are the target for the first year. The customers are Dream Light workers and residential people living in the vicinity of the AD system.

- Digestate

The digestate is expected to have a pH of 7. As the substrate itself should not contain pathogens due to its clean source, the digestate is also expected to be free of pathogens. COD removal is designed to be in the range of 70-75% (Dejene, 2011). The digestate will be sent to the compost pits for solidifying and to use it for speeding up the composting process (from 4-6 months to 1 month) (Dejene, 2011).
Dream Light purchased 100 ha of agricultural land approximately 400 km from Bahir Dar in direction of Gonder. The aim is to use the compost and fertilizer produced on the organic recycling centre there for cultivation of cotton and sesame seeds (Alemnew, 2011).

Figure 45 presents the material flow diagram of the first stage in the recycling project.

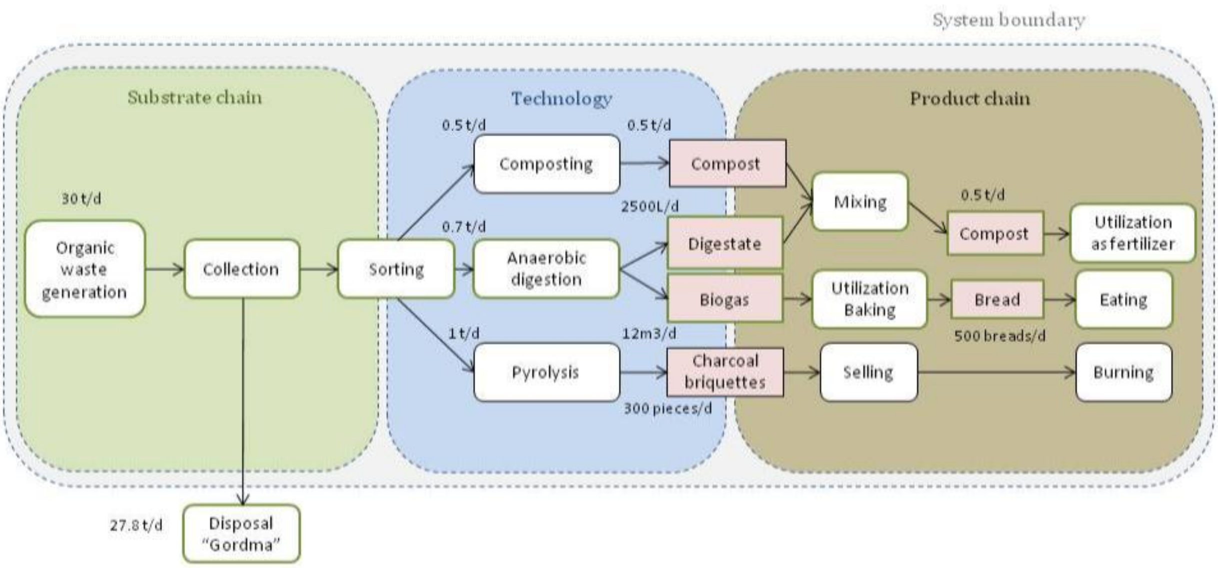


Figure 45: Material flow diagram of Integrated Organic Recycling Centre in Bahir Dar (data from ThiGro Power)

7.4 HOW? (Aspects of enabling environments, sustainability in Bahir Dar)

7.4.1 Synopsis of assessment scores

The tool was applied by filling out the feasibility assessment matrix (see 6.2.4) in October 2011. For that purpose, mainly Dream Light, ThiGro, SNV and the City Administration were consulted and asked for answers. These answers were translated into scores (from -10: not feasible/sustainable to +10: very feasible/sustainable). The complete filled out tool can be found in Appendix VIII. An overview of the scores (without weights) is presented in Table 16 (green: feasible, yellow: neutral, red: not feasible). Additionally, each question that was answered with ‘not feasible’ is mentioned in the table and explained thereafter.

Table 16: Synopsis of assessment scores of AD project in Bahir Dar

#	Feasibility criteria	Score	Questions answered with ‘not feasible’
4.1	**Technological-operational**	**3.5**	
4.1.1	Substrate chain	2.5	Measurement of daily input quantity
4.1.2	AD technology	0.6	Lack of transfer stations; geotechnical conditions, maintenance strategy
4.1.3	Product chain	7.5	Distance from AD site to digestate use, low biogas yield
4.2	**Environmental**	**3.3**	
4.2.1	Use of non-renewable substances	0.0	
4.2.2	Use of chemicals/compounds produced by society	0.0	
4.2.3	Physical degradation/destruction of nature	10	
4.3	**Financial-economic feasibility criteria**	**5.0**	*see details in 4.7.2
4.4	**Socio-cultural feasibility criteria**	**3.3**	
4.4.1	Acceptance	0.0	
4.4.2	Willingness to change behaviour	-	
4.4.3	Conditions that increase people’s capacities	6.7	
4.5	**Institutional feasibility criteria**	**0.8**	
4.5.1	Institutional capacity	- 5.0	Institutional capacity to design, supply materials, build, operate, provide trainings & education, carry out process monitoring and trouble-shooting
4.5.2	Stakeholder cooperation	6.7	
4.6	**Policy & legal feasibility criteria**	**2.0**	
4.6.1	AD policies	2.0	

The following criteria were answered with ‘not feasible’ (Table 16):

- DL intends to measure the daily substrate input to the digester by roughly estimating the waste volume. This way of measurement is considered to be not feasible because it does not take into account daily variation in waste compositions and cannot guarantee appropriate daily feeding load.
- A clear maintenance strategy with description of duties, allocation of responsibilities and frequency of monitoring was not yet envisaged. An explicit and precise strategy on how monitoring and maintenance work will be conducted is absolutely crucial for a positive long-term operation of an AD project.
- Since there is no space for transfer station available in the city, this criteria is also seen as not feasible. Transfer stations are needed for pre-sorting and to minimize the current NIMBY issues with the unofficial collection points distributed throughout the city.
- Due to the very high ground water table, the geotechnical conditions are regarded as not feasible. This situation can lead (and has led) to problems in the construction phase (during rainy season), as it was difficult to keep the digester dry for sealing it with concrete to make it impermeable. Ground water even entered the digester, thereby diluting the slurry.
- The distance between AD site and location of digestate use is approximately 400km which leads to high transportation costs, thus the criterion was assessed as not feasible.
- The proposed biogas yield by ThiGro Power (12m^3/day) is very low compared to literature findings and considering the daily input of substrate: 700kg of wet weight/day with 25% TS and 90%VS = 157.5 kg VS/day, i.e. 76L biogas/kg VS or 51L CH_4/kg VS (very low compared with yields of Table 12).
- There is an apparent lack of institutional capacity (knowledge & experience) of the actively involved stakeholder to design, build and operate such large institutional AD systems. The capacity to provide educational trainings and to carry out process monitoring and trouble-shooting is as well missing.

7.4.2 Cost-Benefit Analysis

The assessment of financial-economic feasibility includes i.a. cost-benefit analysis (CBA) in the form of a net present value analysis (NPV). The following section (Table 17, Table 18, Table 19) presents the details of these financial-economic analyses.

COST-BENEFIT ANALYSIS (CBA)

1. COSTS

Table 17: Results of CBA for project in Bahir Dar: Costs (all figures in ETB)

1	COSTS		1st year	2nd year	3rd year	4th year
1.1	Re-payment of loan	Annual return of loan (incl. 10% interest)	328'117	328'117	328'117	328'117
1.2	Investment costs	Organic Recycling Centre	800'000	73'400	0	0
1.3	Operational costs	a. Salaries	274'800	316'020	363'423	417'936
		b. Electricity	21'600	21'600	21'600	21'600
		c. Water	5'900	5'900	5'900	5'900
		d. Land	5'000	5'000	5'000	5'000
		e. Transport (of compost)	8'587	8'587	8'587	8'587
		f. Maintenance (5% of revenue)	29'500	43'000	95'500	193'000
		g. Miscellaneous (10% of revenue)	59'000	86'000	191'000	386'000
1.4	Other costs	Profit tax (30% of profit)	101'250	202'500	393'750	765'000
1.5	**Total**	**Annual costs**	**1'633'754**	**1'090'124**	**1'412'877**	**2'131'141**

1.0 General

When listing all costs for an AD project, the following categories need to be considered: Re-payment of loan (if a loan has been given), investment costs, operational costs and other costs. These categories are discussed underneath for the case of Bahir Dar.

1.1 Re-payment of loan

UNDP has given Dream Light a loan of 1.6 Mio ETB with a payback period of 4 years. As UNDP feared that Dream Light will not be able to return the full loan including the interest (Dream Light does not yet have collaterals that would guarantee a certain safety for the loan giver), UNDP decided to deduct the 10% interest already in advance (287'532 ETB including compound interest) and keep it (Solomon, 2011). This means that Dream Light received 1.31 Mio ETB which they have to return in 4 years -> 328'117 ETB/y.

The agreement between UNDP and DL is to use this loan 1. for the Organic Recycling Centre (ORC) and 2. for capacity building to improve waste collection (transport, repair collecting trucks, give trainings). This latter post of loan use is also called sustainability issues because it helps to improve the collection service, which is essential for making the Dream Light business economically sustainable (Alemnew, 2011). According to Dream Light, the 1.6 Mio ETB can be considered as loan for the ORC-project (sustainable waste collection is part of it as the revenues for the ORC will be used to pay it back).

1.2 Investment costs

With the loan received by UNDP, the ORC is financed. The site consists of 1 biogas underground fixed dome system (62m^3) with bread backing oven, 1 composting site (150m^3) and a bio-briquetting shed with 3 kilns, 1 hammer mill, 1 mixer and 1 molding machine. Part of the 800'000 is given to the contracted company ThiGro Power for the designs, plans, supervision of construction and trainings, another part was used to purchase the construction materials. In the second year, it is planned to buy one solar dryer (30'000 ETB) for drying of briquetting substrate (during rainy season). An additional post in the second year is two additional kilns (à 21'700 ETB) to increase the briquette production.

1.3 Operational costs

a. <u>Salaries</u>: 29 new labor workers with a monthly salary of 700 ETB and 1 site supervisor & 1 baker (each 1'300 ETB/month) are employed on the ORC. In consideration of inflation and changes in market prices and living standard, a 15% increase of salaries each year is advised (Solomon, 2011).

b. Electricity: 15kW are needed for all machineries for 8h/day → 120kWh/d -> 3'600 kWh/month (Dejene, 2011; Alemnew, 2011). Thus Dream Light has applied for 43'200 kWh/y for which they have to pay 0.5 ETB/kWh. This makes 21'600 ETB/y to be paid to EEPCO (Ethiopian Electric Power Corporation). If Dream Light uses less than the agreed amount of electricity, they have to pay double price per kWh (1ETB). That's why Dream Light will try its best to use the full 43'200 kWh/y (with their hybrid bread baking oven [biogas/electricity] they can increase the bread production to use up electricity. Dream Light does not expect an increase of prices for electricity.
c. Water: According to the ThiGro design, the AD plant requires 1'700L/day of water for dilution of the substrate. An additional 300 L of water is planned for other purposes (like washing hands, tools, machineries). If businesses consume more than 25m^3 of water, the price per m^3 is 8.2 ETB (see Table 7). This makes about 5'900 ETB/y. Dream Light intends to use water from the nearby Abay River (200 m distance) for the AD plant (Alemnew, 2011). However, this requires water pump, hoses, diesel and the site manager feels this would neither be cheaper nor technically feasible (capacity of pump, maintenance, distance from water to AD plant) than using the water from the pipeline (Abrha, 2011). Thus the water price from the pipeline is used for the calculations.
d. Land: Dream Light rents the land of the ORC (10'000m^2) for 0.5 ETB/m^2/y, which makes 5'000 ETB/y.
e. Transport (of compost): Dream Light's agricultural site is in 400km distance from the ORC. 3 times per year the compost will be brought there by one of their waste collection truck. For 5km, the truck uses 1L of gasoline (thus 80L for 400km). 1L of gasoline costs 17.89 ETB. So 3(times/y)*80L (for 400km)*2(ways)*17.89 (ETB/L) = 8'587 ETB/y
f. Maintenance: ThiGro advised Dream Light to calculate the annual maintenance cost by taking 5% of the total annual revenues.
g. Miscellaneous: DL includes 10% of the total annual revenues for unexpected additional costs.

1.4 Other costs
A profit tax of 30% of the net profit has to be paid to the Federal Government. In the Dream Light ORC case, this means 30% of the net profit from bread (0.3 ETB/bread) and bio-briquettes (1 ETB/briquette).

1.5 Total annual costs
All costs added up result in the total annual cost to be paid by Dream Light.

2. BENEFIT

Table 18: Results of CBA for project in Bahir Dar: Benefits (all figures in ETB)

2	*BENEFITS*		*1st year*	*2nd year*	*3rd year*	*4th year*
2.1	Revenue	a. Bread	150'000	300'000	450'000	600'000
		b. Bio-briquettes	180'000	300'000	1'200'000	3'000'000
2.2	Savings	b. Chemical fertililizer	260'000	260'000	260'000	260'000
2.3	**Total**	**Annual revenue**	**590'000**	**860'000**	**1'910'000**	**3'860'000**
2.1.1	*Net profit*	*a. Bread*	*37'500*	*75'000*	*112'500*	*150'000*
		b. Bio-briquettes	*300'000*	*600'000*	*1'200'000*	*2'400'000*
		Total annual net profit	*337'500*	*675'000*	*1'312'500*	*2'550'000*

2.0 General
When listing the revenues of an AD project, the following two categories need to be considered: Revenue from products, and savings. In the case of Bahir Dar where a profit tax needs to be paid, the net profit has to be calculated.

2.1 Revenue
a. Bread: The bakery is expected to produce 500 breads/day (50 kg flour) in the first year. Bread baking will be on 25 working days/month during 12 months/y and the bread will be sold for 1 ETB/bread. The bread production in the 2nd year is expected to be 1000 breads/day, in the third year 1500 breads/day and in the fourth year 2000 bread/day. This increase in bread production is expected to be the result of higher working efficiency and improved combination of hybrid use (biogas and electricity).

b. <u>Charcoal-briquettes:</u> The first trials on one kiln have shown that the earlier assumptions have been far too optimistic (they were all based on the assumption that the capacity of the hammer mill is the limiting factor. But is turned out that the charcoal production in the kilns is the rate limiting step). The first experiment has led to the following result: 210kg of risk husks was packed in one kiln and after 3 days of substrate pyrolysis, 51kg of coal powder remained (24% of the input). By improving the pyrolysis process (initial oxygen inflow, better gas tightness), it is expected to reduce the process time to 2days and increase the efficiency to 30% of input). With 3 kilns, this means that 630kg of substrate can be processed, producing 180 kg of char powder in 2 days (or 90kg in 1 day). As 1 briquette weights 0.3kg, 300 briquettes can be produced with the current infrastructure (3 kilns). Hence 300 briquettes will be produced on 25 working days/month during 12 month/y. Each briquette will be sold for 2 ETB → 180'000 ETB revenue/y. In the second year (after the installation of 2 additional kilns, the briquette production will be increased to 500 briquettes/day. In the third year, a briquette production of 2000 briquettes/day is expected and in the fourth year 5000 briquettes should be produced daily. This increase in production is expected from higher working efficiency, advanced/adapted technologies (based on pyrolysis experience) and maybe additional capacity of kilns (size or in number, included in miscellaneous costs).

2.2 Savings

Dream Light has rented 100 ha of agricultural land and intends to cultivate mainly sesame there for oil production. 200 kg of artificial fertilizer is required per ha/y. The price of 100kg artificial fertilizer is 1300 ETB. Thus Dream Light would have to spend 2*1'300*100 = 260'000 ETB on artificial fertilizer, but they save this amount of money by using their own mix of compost and digestate.

2.3 Total annual revenue

All revenues added up result in this total annual revenue of Dream Light.

<u>2.1.1 Net profit</u>

a. <u>Bread:</u> For calculating the profit tax, the net profit of bread and briquette production had to be identified: For the bread the figures are as follows:

- *A baker has to spend 7 ETB for 1kg of flour including the necessary yeast. In Dream Light's case (1st year), they bake 500 breads per day (50kg of flour needed). Thus 50*25 (working days/month)*12 (months/y) = 105'000 ETB/y for flour and yeast. This means 0.7 ETB has to be spent per bread.*
- *For firewood, the information was found that to bake 50kg of flour (500 breads/day), expenses of 27 ETB is needed for firewood. This adds up to 8'100 ETB/y for 150'000 breads (0.05 ETB/bread).*
- *1 baker will be employed to bake these 500 breads/day. His annual salary is 15'600 ETB. With an annual bread production (1st year) of 150'000 breads, 0.1 ETB/bread have to be subtracted for his salary.*

➔ *Combining these three posts (flour/yeast, firewood saving, baker's salary) Dream Light's net profit is 0.25ETB/bread from 1 ETB of revenue/bread.*

b. <u>Briquettes:</u> The briquettes will be sold for 2 ETB/piece. The net profit is expected to be 1 ETB/briquette (Alemnew, 2011; Dejene, 2011). The other 1 ETB is costs for machineries, salaries, price of substrate.

3. COST-BENEFIT

Table 19: Results of CBA for project in Bahir Dar: Cost-benefit (all figures in ETB)

3	*COST-BENEFIT*		*1st year*	*2nd year*	*3rd year*	*4th year*
3.1	**Economic benefit**	**Annual revenue minus annual costs**	**-1'043'754**	**-230'124**	**497'123**	**1'728'859**
3.1.1		*Cumulative net cash flow*	*-1'043'754*	*-1'930'112*	*-1'104'873*	*952'104*

3.1 Net cash flow

The cost-benefit balance (net cash flow of the company) is calculated by subtracting the annual revenues from the annual costs.

3.1.1 Cumulative net cash flow (breakeven point)
To calculate the breakeven point, it is not valid to simply add all annual net cash flows. The part of the annual loan which is not returned yet has to be taken into consideration as well. This has been done under cumulative net cash flow and it shows that starting from the 4th year of operation, the company will be generating net profit from this ORC project.

4. NET PRESENT VALUE (NPV)
In order to account for the time value of money, the values obtained from the CBA were used to calculate the net present value (NPV).

Table 20: Net Present Value analysis for project in Bahir Dar

t	*Cash flows at time t*		*Rt*	*(1+i)^t*	*NPV*	*Cumulative NPV*
Time	*Inflow*	*Outflow*	*Net cash flow*	*Discount rate at time t*	*Rt/(1+i)^t*	∑ Rt/(1+i)^t
0	0	800'000	-800'000	1.00	-800'000	**-800'000**
1	590'000	833'754	-243'754	1.10	-221'595	**-1'021'595**
2	860'000	1'090'124	-230'124	1.21	-190'185	**-1'211'780**
3	1'910'000	1'412'877	497'123	1.33	373'496	**-838'284**
4	3'860'000	2'131'141	1'728'859	1.46	1'180'834	**342'550**

In Table 20, 10% was used for the rate of return (i). As the cumulative NPV already after 4 years (payback period of loan) is positive and maintenance costs are not to be expected to outweigh revenues, further NPV calculations of the next years were not considered. This implies that an investment in this ORC-project makes sense from an economic point of view.

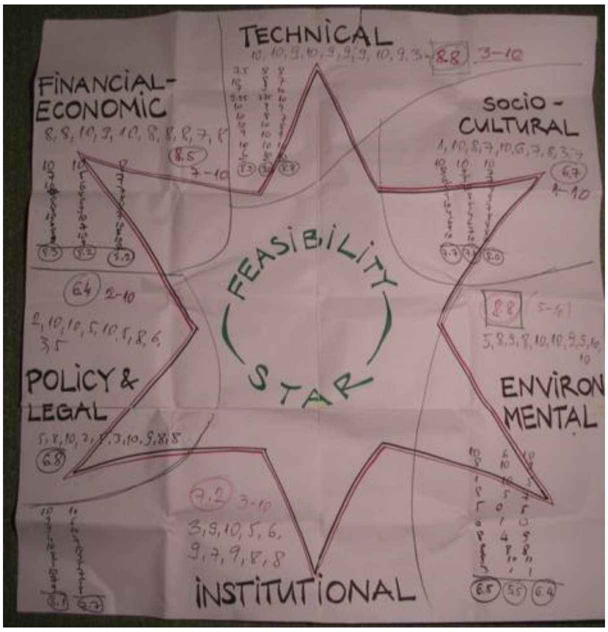
7.4.3 Adaptations of tool based on stakeholders feedbacks

A stakeholder workshop was organized that took place on Tuesday, 25 October from 9:00 - 12:00 in the meeting hall of SNV in Bahir Dar. The aim of the workshop was to test the feasibility assessment tool on the organic recycling centre of Dream Light and thereby receiving feedback on how to improve the tool and how to adjust the proposed project to make it more sustainable. Appendix XI presents the invited stakeholders and indicates the ones who participated in the workshop.

The limited number of invited participants was chosen so that a plenary discussion is still possible. The participants were selected by making use of the stakeholder power-interest matrix (Figure 43). The selection of stakeholders was guided by the criteria, if their *power* and *interest* is in function of sound operationality of the proposed AD system. All stakeholders with high power were invited as well as a selection of governmental authorities (CA, AE&M, BoEPLAU, BoH, BoUD) and research institutes (BDU, ARARI). UNDP was invited representing the funding agency of the project. SNV not only hosted the meeting but also represented an organization with knowledge and practical experience in Ethiopian AD. Waste generators, bakeries and informal recyclers could unfortunately not be invited due to a lack of organizations representing these groups.

The workshop was started with a brief welcome and introduction round. A presentation of Dr. Lijljana Rodić explained the role of AD within the SWM system. Subsequently, the feasibility assessment tool was introduced and the AD project in Bahir Dar presented. The stakeholders were then asked to assign weight to the six feasibility criteria groups and their sub-criteria.

The participants were asked: *"In your opinion, how important is each one of these six main criteria and sub-criteria for the success of an anaerobic digestion (AD) project?"*
Each participant then gave weights between 1 and 10 (1: criteria not important at all, 10: criteria essentially important). These weights and the assessment procedure were discussed at the end of the workshop.



The weighting procedure was done anonymously by means of small papers that were distributed and later on collected again.

A ‘feasibility star’ drawn on a large paper (1.2m * 1.2m), which had been prepared previous to the workshop, was hung on the wall to present the weights given by the stakeholders. All individual values were noted to show the range of answers, all mean values of the main criteria and the sub-criteria were calculated and noted down to present the average weights (Figure 46).

This working document formed the basis for the discussions that followed afterwards.

Figure 46: Working document “feasibility star” used during stakeholder workshop in Bahir Dar

The following list includes the stakeholders’ feedbacks related to the workshop in general and to the presented tool and method:

<u>General feedback about workshop</u>

- Such stakeholder meetings are widely appreciated. It is a common perception that SWM encompasses many different stakeholders and that a wide range of stakeholders can contribute positively to the success of an AD project, if they all pull together. ARARI and EPA declared that it is the CA’s responsibility to organize such meetings.
- BoH complained that they have not been involved in any aspect in the development of the ORC by Dream Light. It was through this thesis work that they actually got to know about it.
- ARARI stated that building up understanding of the complete value chain (from waste to energy and digestate) is a very important success factor
- Two relevant stakeholders were mentioned to be missing: LEM Ethiopia (experiences in SWM and biogas projects) and GIZ (experience in renewable energy sector)

<u>Feedback about feasibility assessment tool and method</u>

- The majority of stakeholders would have preferred to do the weighting procedure openly and transparent. This would have allowed discussions about the different perspectives/priorities and could have helped to avoid misunderstanding.
- It was not clear how the sub-criteria should be rated in comparison to the six main criteria groups.
- There was a widespread misunderstanding about what the meaning of weights is: Many stakeholders understood that scores rather than weights were asked for, so they related their rating to the concrete AD project (e.g. they asked themselves: Is the proposed Dream Light project environmentally friendly? If yes, they would assign a high number. Others would assign a low number to this criterion because the impact of the concrete DL project on the environmental was considered to be low).
- The differences between weights given to the main criteria and to the related sub-criteria were big, which was an indication that the weight-giving bas based on a misunderstanding.
- The main categories were interpreted different from their initial intended meaning. They should be explained in such a way that everybody has the same picture of what they stand for. The sub-criteria can be briefly mentioned for better description of the main criteria. It was said that *“When detailed information is provided, one can give more detailed opinion. Thus providing explanations for each criteria leads to more appropriate weights given.”*
- It was reported that assigning weights to the main criteria is sufficient, sub-criteria don’t need separate weighting.

- Socio-cultural criteria (especially acceptance and willingness) are seen as particularly crucial for this and similar projects (CA, BoH, SNV, EPA…)
- SNV mentioned that the institutional criteria are very good as they encompass not only the available capacity, but also include the collaboration between the stakeholders which is of crucial importance.
- In terms of policy & legal criteria, different stakeholders stated that not the existence of legislation itself is the problem, but enforcement is the critical issue. It was therefore suggested to add a question pertaining to enforcement practices.
- Environmental criteria (TNS) were considered to be unclear: It was not understood that the questions relate to contamination of all environmental compartments (water, soil, air). These three compartments should be explicitly stated.
- It has to be clearly stated and explained that knowledge, awareness and ability of the community is also addressed in the tool.
- All stakeholders agreed that the combination of proper technology selection and availability of related institutional capacity is crucial to make technology operational.

These feedbacks resulted in modifications of the tool in terms of assessment procedure and concrete changes in formulations. Major adaptations that have been conducted during the process of working on this thesis and the reasons behind these changes are presented hereafter.

As the intended procedure of assigning weights to the feasibility criteria groups created some confusion, an improved process in the stakeholder workshop is suggested. This helps to clarify the differences between scores and weights:

1. Present the results of the feasibility assessment matrix (HOW) by showing the scores. A brief discussion about the results and how the data was collected will demonstrate a.) the difference between scores and weights and b.) that the actual scoring has already been done and c.) that the expected contribution of the stakeholders is to assign weights to the main criteria.
2. Ask stakeholders for weights of the main criteria by giving sub-criteria as descriptions (see Appendix X for modified weighting-sheet for stakeholders)
3. Present feasibility results (weighted scores) of different stakeholders
4. Discuss differences in results and search for improvements of the proposed AD set-up

The idea behind the discussion is not to reach consensus among the stakeholders under all circumstances, but to reveal opposing positions that might endanger a successful outcome of the project. If a compromise can be found based on the revealed positions, all the better. If not, the decision has to be made if the conflicting ideas and priorities are still sufficiently acceptable to continue with the project.

7.4.4 Feasibility of AD project in Bahir Dar

Figure 47 presents the overall feasibility of the AD project as proposed in Bahir Dar. The depicted bars combine the scores from the feasibility assessment matrix and the average weights given by the stakeholders. None of the six main criteria received average feasibility in the negative range. While financial-economic feasibility was assessed to be good, technological-operational, environmental and socio-cultural feasibility also received acceptable feasibility results. In contrast, institutional feasibility was assessed to be low which is mainly due to the very low scoring in the sub-category 'institutional capacity' (see Table 16). The result in the category policy & legal category is as well below 20 with a considerable uncertainty range indicating that current policies are rather neutral in regard to AD and it's difficult to predict if future policies, rules and regulation will be supportive or disruptive for AD projects.

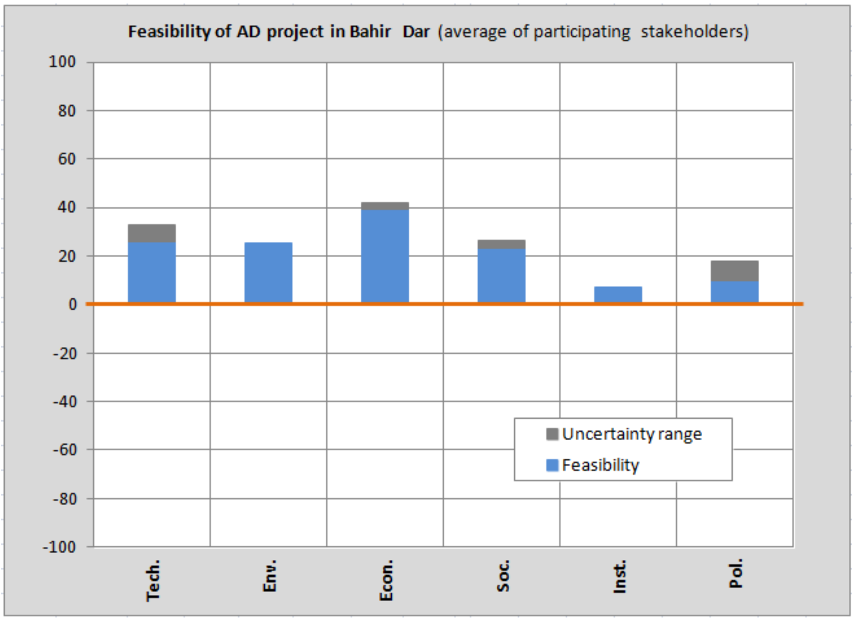


Figure 47: Feasibility of AD project in Bahir Dar (product of scores and average weight of all questioned stakeholders)

In the presentation of general feasibility results as depicted in Figure 47, some important information is lost, namely the different perspectives (weights) of the stakeholders. For that purpose, the tool provides a second visualization method for comparison of different stakeholders' priorities.

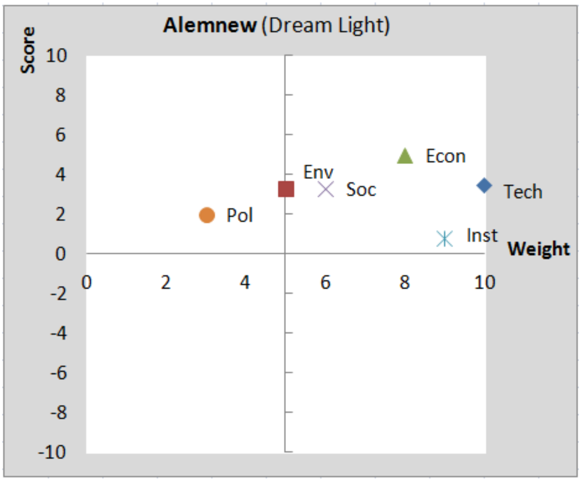


Figure 49: Feasibility of AD project in BD from perspective of Alemnew (DL)

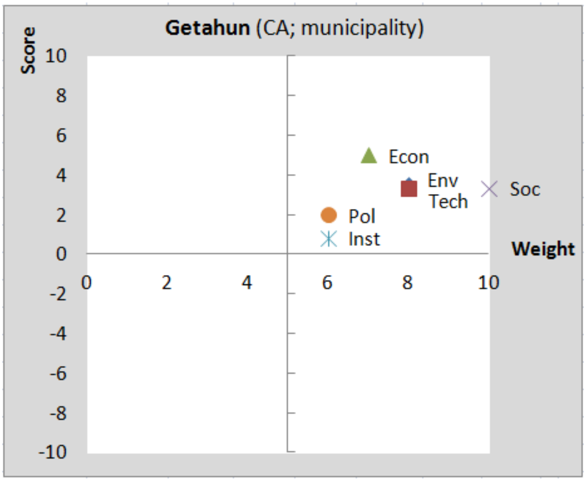


Figure 48: Feasibility of AD project in BD from perspective of Getahun (CA)

Figure 49 reveals the assessment from the perspective of the project initiator (Dream Light): Technological-operational feasibility criteria are considered to be most relevant for the success of the AD project. Together with financial-economic, social and environmental criteria, this category received (positive) average scores indicating that the proposed set-up is feasible in this regard. DL rated institutional criteria as second most influential criteria in terms of outcome of the project. Due to the relatively low score, special emphasis is asked on improving the institutional capacity of the involved stakeholders to ensure this will not become a problem for sound long-term operation of the system.

In comparison, Getahun from the municipality considers social criteria to be most important in AD projects (Figure 48). Taking into consideration the close dependency of these two major stakeholders (DL and CA), it is crucial for DL to find out on which basis this high weight was given by CA for socio-cultural feasibility criteria. Does it indicate specific expectations of the municipality towards the AD project or is it based on earlier experiences with similar projects? Discussion of such issues can be a crucial piece in jointly working on putting together a successful AD puzzle.

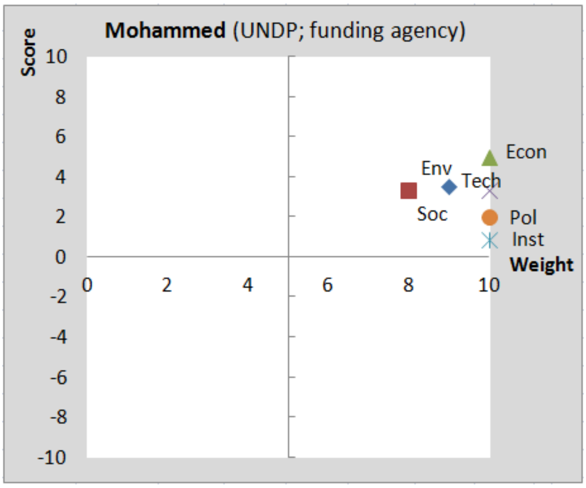


Figure 51: Feasibility of AD project in BD from perspective of Mohammed (UNDP)

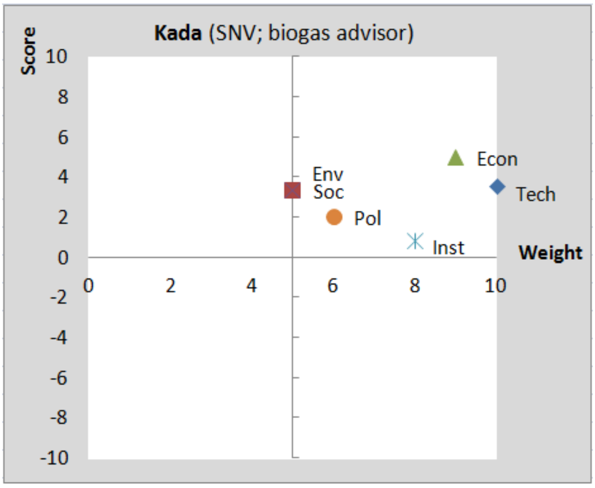


Figure 50: Feasibility of AD project in BD from perspective of Kada (SNV)

Figure 51 reveals the perspective of the funding agency (UNDP) of the AD project in Bahir Dar. It can be seen that all main criteria were given high weights (8-10), implying that they all are considered almost equally important for the positive outcome of the project. Again here, institutional feasibility was ranked as one of the most relevant criteria, which due to its low score draws particular attention on it.
The technical biogas advisor of SNV (Figure 50) rates the importance of the criteria similar to DL but gives higher weight for policy & legal criteria.

In three out of these four stakeholders' assessments, the criteria can all be found in the upper-right quadrant, indicating that all six criteria received positive values and all of them are regarded as exerting a considerable influence on the outcome of the project. In contrast, criteria that would be found in the bottom-right quadrant would signify a major threat to the AD project (Red flag).

All in all, the AD proposed project in Bahir Dar shows a good overall feasibility (with certain attention required particularly on institutional capacity building and inclusion), but also that most stakeholders value all the different criteria relatively high. They thereby indicate their realization that such a project has to be assessed from different points of views and various issues need care and attention during the planning, operation and maintenance phase.

8 Discussion

8.1 Conceptual framework

The conceptual framework of this thesis research consisted of the following elements: Reflexive engineering approach, sustainability concepts, integrated sustainable waste management (ISWM) and methodology developed by UN-Habitat for analysis of solid waste management (SWM), anaerobic digestion (AD) of biowaste and feasibility assessment theories. The idea behind this conceptual framework was to provide theoretical inputs for all relevant pillars of the research and to serve as a map that gives coherence and guidance to the research procedure. To ensure that the framework is complete and at the same time does not contain unnecessary items, the following two points were examined:

- Can all research questions be answered by means of the information from the chosen elements?
- What is the relevance of each element in function of answering the research questions?

Overall, the conceptual framework turned out to be suitable for this thesis work as all research questions could be answered in a structured manner and all elements of the framework contributed to doing so:

- ***Reflexive engineering approach**:* This approach, which demands a flexible attitude and a holistic understanding of socio-technical dynamics, was an inspiring and useful guideline. As it sees a broad range of stakeholders as resource and partners in decision-making, it was a permanent reminder that experiences, needs and views of these stakeholders play a central role. Thus an open atmosphere of mutual learning was always striven for by encouraging and valuing each individual input. The reflexive engineering approach proved its merit in this research as it enabled adaptation of the intended procedure in accordance to the demands of the stakeholders in Bahir Dar, as elaborated below in the discussion of the value of the fieldwork.
- ***Sustainability concepts:*** The framework named 'The Natural Step' (TNS) with its four system conditions (principles) of sustainability provides a neat, straightforward and yet comprehensive set of criteria to assess environmental sustainability and to test social sustainability based on the scientific foundation of the laws of thermodynamics and studies of humans as a social species. However, it became apparent, that the formulations as directly taken from TNS remain too abstract for many stakeholders to grasp the whole meaning behind. For example, stakeholders did not realize that this concept addresses contamination of the three environmental compartments (soil, water and air). Thus the concept had to be translated into a more comprehensible, more conventional language.
- ***Integrated sustainable waste management (ISWM) combined with the UN-Habitat methodology*****:** Both methodologies of ISWM and UN-Habitat contain distinct strengths. ISWM distinguishes three dimensions, which answer the questions WHO (stakeholders), WHAT (system technical components) and HOW (enabling environment/sustainability aspects). Although the UN-Habitat framework is based on the ISWM concept, its focus is somewhat different, thus its structure gives answers to the questions WHY (development drivers/state of modernization), WHAT (system technical components) and HOW (governance). In combination, the two frameworks provide a very useful and comprehensive structure (WHY, WHO, WHAT, HOW), for analyzing waste management systems in a systematic way and for finding appropriate contextual solutions based on the results derived from the analysis. This structure also laid the basis for the development of the feasibility assessment tool.
- ***Anaerobic digestion (AD) of biowaste**:* Information found in literature about AD process and technologies provided a solid basis of technological Know-How and helped to get an overview of the important components of an AD system and defining technology-related issues in the feasibility tool. However, integration of all this information into the report was difficult as many insights were not directly useful for the modified tool. This would have been different if the initial plan to develop different technological scenarios for assessment had been followed. Creating a complete overview of AD technologies in low-, middle- and high-income countries not only turned out to be too ambitious in respect to the given time, but also proved to have only limited benefit for the thesis at hand. As it led to a lack of depth in presenting the technologies, particularly those implemented in industrialized countries, it would have been better to exclusively focus on AD technologies in developing countries as these are the options that have proven to be most promising and suitable in this context. Specific

information about how AD technology assessments can be conducted in a systematic way was not found, which made it harder to systematically evaluate AD projects visited in Ethiopia.

- The proposed visual classification model was developed to enable quick understanding of the most important characteristics of an AD technology for biowaste. However, it was realized that particularly in the developing country context, where often only three different technologies are used (fixed-dome, floating-dome, tube digester), the visualization model was of limited use as these three technologies hardly show any differences in terms of the chosen technology characteristics (Figure 52) . This demonstrates the importance for other characteristics in deciding if a technology is suitable. Thus it justifies the need for a tool that besides technological-operational, also includes environmental, financial-economic, socio-cultural, institutional and policy & legal feasibility criteria.

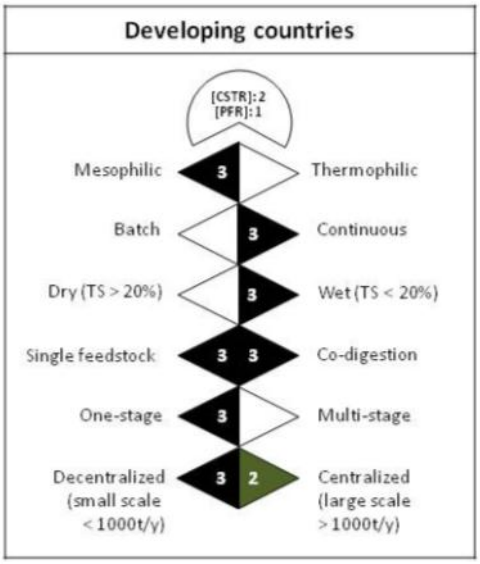


Figure 52: Characteristics of three AD technologies predominately implemented in developing countries

- ***Feasibility assessment****:* Screening literature for different feasibility assessments revealed that the traditional business-centred feasibility tool TELOCS (Technical, Economic, Legal, Operation, Cultural and Schedule aspects) is biased towards views and interests of one stakeholder only - a company that is interested in developing a certain business case. However, it was important to develop a tool that not only includes the perspectives of other stakeholders in the assessment process, but also to move towards a more holistic sustainability paradigm where externalities are taken into consideration. Thus the traditional business-centred feasibility assessment theories from literature were only of limited direct use. The Multi Criteria Decision Analysis (MCDA) provided a widely accepted and used decision-making method for problems that includes quantitative and qualitative aspects. As the research shifted from comparing different scenarios and technologies to assessing one concrete project proposal, the step *'identifying the options to be appraised'* was excluded from the MCDA of this thesis. Obviously, all assumptions that are part of MCDA are also transferred into the developed tool.

8.2 Methodology and research procedure

The overall objective of this thesis was to develop a feasibility assessment tool for anaerobic digestion technologies treating municipal biowaste in developing countries and to subsequently apply the tool in Bahir Dar. The whole research was designed in such a way that it is comprehensive. First, all relevant concepts for this research were identified by means of an extensive literature review. Based on these concepts, a complete questionnaire was derived. This questionnaire was finally tested in the field.

<u>The literature study</u> first enabled an overview and fundamental grasp of the topics relevant for this research. By subsequently going into more detail and acquiring state-of-the-art insights of sustainability, SWM, AD and decision making, the elements for the conceptual framework were distilled. This was done by viewing, combining and filtering theoretical knowledge found in diverse literature sources, all with the objective/criteria to adequately answer the research questions.

<u>The fieldwork</u> allowed the examination of the gained knowledge under specific local circumstances. More explicitly, the 3-months-fieldwork enabled a reality-check of the theoretical insights and the developed literature-based tool by applying and testing it in the context of Bahir Dar. Furthermore, the fieldwork allowed discussion with the involved stakeholders so that the tool could be adapted by integrating the concerns, advices and comments of these stakeholders. As mentioned before, this corresponds to the reflexive engineering approach that aims at mutual learning by regarding a broad range of stakeholders as resource and partners in decision-making, which demands a certain degree of flexibility from the researcher.

This approach enabled the adaptation of the intended procedure in accordance to the demands of the stakeholders. The initial intention to create a tool for parties interested in *evaluating general feasibility of AD for biowaste and recommend a technological set-up* was dismissed in favour of creating a tool that can *assess a specific AD project (proposal).* The project in Bahir Dar was in a more advanced stage than expected prior to the start of the fieldwork. It was expected that only vague plans exist for the development of an AD system in Bahir Dar. However, the situation encountered in the field was quite different: Construction of the biogas digester was almost completed and plans already existed for the next up-scaling stage of the project. In discussions with the involved stakeholders (partners in decision-making) it became apparent, that a tool for assessing the proposed project is much more desired. Thus the focus shifted from supporting the stakeholders in Bahir Dar to find out which technology is the most appropriate (by developing different scenarios and ranking their strengths and weaknesses), to assessing the concrete project as proposed in Bahir Dar and finding out how its sustainability can be ensured or further improved. Thus instead of strictly following the researcher's initial plan, the procedure was changed so that a tool could be developed which corresponds to the explicit demands of the stakeholders under the given circumstances. Moreover, this tool now allows the local stakeholders to come up with a technological AD set-up themselves instead of the researcher suggesting a certain technology in a top-down manner. In other words, it gives more credit to ideas and needs of the involved stakeholders.

Recapitulating, the 'reflexive engineering approach' was helpful for the researcher and well received by the stakeholders as it embraces a spirit of holistic thinking and mutual learning. It should however also be mentioned that this approach inherently requires quite some flexibility of the researcher in correspondence to the multifaceted and changing social, environmental and economic circumstances. Thus adaptations of the intended procedural steps are not only almost inevitable, but should also be embraced, as they contribute to the acceptance and usefulness of the tool for the stakeholders involved.

Further methodological points that proved to be beneficial are:

<u>Fieldwork research started by first putting efforts into understanding the SWM in a city in detail</u>. This resulted in being able to draw a Process Flow Diagram (PFD) and a stakeholder matrix of the system, i.e. to get an overall picture of the current solid waste system at a glance, before diving into the feasibility assessment of AD. PFD, which illustrates the service providers, process steps and movement of waste material streams, has several distinct advantages: All waste streams are accounted for, losses are exposed, system boundaries are clearly denoted, no activities forgotten, final destinations of waste materials are stated, and the place and contributions of all stakeholders are visible. However, a PFD requires data about waste quantities which might be difficult to get. In the case of Bahir Dar, these data were available due to the previously conducted UNEP-study. The stakeholder-matrix quantifies and visualizes the power and interest of each stakeholder in the SWM. The combined results of a PFD and stakeholder-matrix are important as they delineate the context in which the AD project takes place and furthermore present promising partners and points of interventions. Both methods proved to be very helpful for incorporating a large quantity of diverse information into a clear and comprehensible scheme.

Interviews were used as the main research method in the initial stage of the fieldwork. This allowed the researcher to become acquainted with the individual stakeholders, the socio-cultural behavior (e.g. the culturally accepted communication path for meeting arrangements) and showed a mutual openness to listen and learn rather than impose an opinion or a strategy in a top-down manner. This approach has probably also contributed to the satisfactory participation and cooperation in the stakeholder workshop. It also became evident that personal contact is an essential prerequisite for a successful collaboration. The mails that the researcher had sent to SWM- and AD-stakeholders in Bahir Dar prior to the fieldwork almost exclusively remained unanswered, whereas the collaboration and exchange of information once in Ethiopia went very smoothly.

<u>The collaboration with Dream Light (DL) was excellent</u>. DL's openness to share information, ideas and concerns enabled a smooth and efficient working process. It proved to be beneficial that other researchers (from Sandec/Eawag) have already established a trustworthy relationship with the company. Moreover, it was clear that both parties (DL and researcher) benefit from a good and candid exchange.

The stakeholder workshop led to improvement of the tool and was well received. Although a stakeholder workshop is not absolutely necessary for performing feasibility assessment (the opinions about allocation of weights can be collected individually from stakeholders), the realization of the workshop in Bahir Dar was an important technique to test and improve the tool. Not only did it allow stakeholders to assign weights to the different main feasibility categories, but it also resulted in a discussion about lack of clarity pertaining to the tool and suggestions for improvements. In addition, the feedback of the stakeholders revealed unclear formulations and flaws in the assessment procedure. The workshop underlines the benefit of having chosen a reflexive approach, in which education is seen as a two-way process between the researcher and the communities.

The analysis of SWM and AD feasibility uses the same structure. The fact that the same structure was used for assessing SWM and AD feasibility speaks for its versatile applicability. The four questions WHY, WHO, WHAT and HOW, that were developed by combining the methodologies of ISWM and of UN-Habitat, turned out to be a very suitable guideline for any systemic approach to the analysis of solid waste management activities (or in general when intending to describe or assess a system).

The planning was appropriate for the fulfillment of the tasks (see 3. Methodology, p. 17 and Appendix I). While the first two months were required for the literature study, the three months in the field were necessary to first get adapted to climatic, logistic and socio-cultural circumstances, and subsequently have sufficient time to collect all relevant information, apply the feasibility assessment tool and finally process the feedbacks of the stakeholders. Especially the two buffer-weeks, which had been scheduled to compensate for unforeseen developments, proved their merits. As preparation of the interviews and frequent visits to observe the construction process at the organic recycling site (including transportation) was more time-demanding than expected, putting the results into a report-format had to be done during the buffer weeks.

The methodological points that could be improved are:

Translation of general questionnaire (about SWM and AD context) into exact questions: The general questionnaire (presented in Appendix IV) was used to interview all stakeholders, whereas to formulate exact questions in each case would have been more accurate and easier for the researcher to process the answers. In addition, a slightly more confronting attitude with more inconvenient questions might have generated additional interesting data.

Exchange of information between students doing research about SWM in Bahir Dar: This thesis formed one part of a research project by Eawag/Sandec consisting of three consecutive studies. As all three studies were about SWM in Bahir Dar (financial sustainability of current system, analysis of informal recycling sector, feasibility assessment for AD), it would have been beneficial to integrate the results of the two previous studies in this thesis. However, exchange of information between the three students was unsatisfactory. Delay in the research activities made it impossible to utilize these results. This led to an unexploited use of potential synergies and to some extent resulted in duplication of work. It is advisable to schedule certain dates already at the beginning for specified exchange of data.

8.3 Feasibility assessment tool

Taking into consideration that conducting a feasibility assessment previous to an AD project *at all* is still far from being a norm in developing countries (let alone including sustainability criteria), this tool can be seen as a valuable contribution to filling this gap. The tool has several distinct strengths.

The tool developed in this research study has achieved the multiple aims defined at the beginning. The specific initial aims for developing such a tool are listed underneath and briefly explained if and how the intentions have been reached.

- ***Is well structured and contains a clear logic:*** One of the strengths of the tool is its clear structure, formed along four dimensions of WHY, WHO, WHAT, HOW. These dimensions and the feasibility assessments' six criteria are based on the well-established and widely applied ISWM structure (with integrated elements from UN-Habitat) to analyse the sustainability of a solid waste system, thus makes it easier for practitioners with a background in SWM to work with.

- ***Uses sustainability as feasibility criteria***: The feasibility assessment uses the six sustainability criteria of the ISWM framework: Technological-operational, environmental, financial-economic, socio-cultural, institutional and policy & legal. These are appropriate as they cover all relevant aspects that have to be considered for an AD project. The Natural Step (TNS) framework was chosen as it provides a scientifically proven concept of how environmental (and social) sustainability can be assessed.

- ***Uncovers requirements for successful AD projects***: The tool is comprehensive i.e. it consists of an extensive set of questions that require a mix of relevant quantitative and qualitative information, thereby presenting a checklist for AD projects. In this regard, one can almost say that *"the way is part of the goal"*, or in other words: Working through the tool uncovers important requirements and raises the awareness of the involved stakeholders. Another strong point of the tool is the use of 'red flags' which appear when certain crucial questions are answered in a way that it constitutes a potential project breaker. In such case, an intervention is required i.e. the issue needs to be addressed, cleared and improved in collaboration with the respective stakeholders before continuing with the tool.
  To ensure that the tool is comprehensive, all relevant concepts for this research were identified by an extensive literature review. An elaborate questionnaire was subsequently derived based on these concepts and finally the tool was tested in real life on the project in Bahir Dar.

- ***Reveals differences in stakeholder perspectives and priorities:*** The tool requires the involvement of stakeholders. They are not only consulted in order to find answers to the set of questions, but they are also asked to state their perspectives in terms of how important each criterion is for a successful outcome of the AD project under discussion. The different views can be expressed and their consequences can be jointly elaborated in a stakeholder workshop.

- ***Creates basis for discussion:*** The stakeholders are asked for their *knowledge*, but also their *opinion* is equally important and thus appreciated. This appreciation was experienced to be helpful in motivating stakeholders to contribute to the success of the project. The different opinions are visualized in a graph, which facilitates discussions.

- ***Quantifies feasibility:*** The developed tool includes a simple mathematical algorithm that combines the outcomes of the feasibility assessment done by the expert in consultation with the stakeholders (scores) with the importance of the different feasibility criteria attributed by the stakeholders (weights). Furthermore, the risk that things develop differently than planned or that the data used for the assessment is not reliable (uncertainty factors) is also included. Uncertainty is quantified in such a way that the products of scores and weights can be reduced to half their values if the risk of uncertainty is considered to be very high. The proposed algorithm can be seen as a first attempt to quantity uncertainty, but can surely be refined in further studies. A strength of the tool is that each of the six feasibility criteria (technological-operational, environmental, financial-economic, socio-cultural, institutional and policy & legal) can be assessed individually, for instance the assessment of socio-cultural feasibility generates an independent number that indicates how feasible the proposed project is in terms of this aspect. In the process of combining the scores of all criteria to arrive at an overall average score, the red flags prevent that important information (e.g. unfeasible performance in one of the categories) is lost or can be compensated by a criteria that performed well.

- ***Enables testing the capacity of the institution responsible for design & installation of the system:*** As mentioned above, an extensive set of questions needs to be answered. To do so, the company responsible for design and installation of the system is contacted and asked to help in finding these answers. An indication for low institutional capacity can be if the answers cannot be provided or if they deviate considerably from reliable literature data.

- ***Is general enough to allow assessing the whole variety of AD technologies for biowaste and specific enough to deliver precise results corresponding to the local context:*** The tool has been successfully tested in Bahir Dar. Before being able to make a concluding statement about the applicability to a wide range of technological set-ups, the tool has to be further tested.

- ***Can be used for comparison of AD technologies**:* The results of the feasibility assessment, visualized in the diagrams, enable comparison of AD proposals with different technologies.
- ***Helps to increase sustainability of projects proposed**:* As the tool generates an overview of the strengths and weaknesses of a proposed project, it supports the first step of increasing sustainability: The realization (understanding) of where improvement is needed and possible.

The following points refer to the tool's applicability and its potential for application:

The person doing the assessment needs to be knowledgeable about AD. One of the initial ideas was to develop a tool that can be used by any interested stakeholder. However, it was soon obvious that certain in-depth knowledge about AD is prerequisite. As it is now, the tool is meant to be used by an AD expert who, in collaboration with involved stakeholders, can assess the feasibility of a project proposal.

A certain extent of subjectivity remains when applying the tool. The answer categories (HOW in performance matrix) in some cases do not provide clear-cut and objective answers, hence the tool is prone to subjectivity as the person conducting the assessment consciously or unconsciously exerts a certain influence on the outcome of the assessment. On one hand, the subjectivity component of the tool can be regarded as weakness; on the other hand some degree of human subjectivity is a fact that is inherent in assessment procedures and in decision-making processes. If the assessment is done transparently, each answer (score, weight and uncertainty factor) can be discussed openly in the group and thus risk for deliberate manipulation can be minimized.

The stakeholders welcomed the workshop and engaged in an open and transparent process of allocating weights of the feasibility criteria. Although a stakeholder workshop is not absolutely necessary for performing feasibility assessment (weights can be collected individually from stakeholders), its realization of the workshop in Bahir Dar was a very important step in the development of the tool. It is positively surprising that the stakeholders-participants of the workshop in Bahir Dar preferred an open and transparent process of weights-allocation over an anonymous procedure. It was argued that this helps to prevent misunderstandings and enables fruitful discussions. The researcher's initial doubt if stakeholders are willing to openly share their opinions and priorities was unfounded. This is seen as important and positive, because it indicates an open atmosphere in which stakeholders are willing to share and learn from other parties, a pre-requisite for the targeted mutual learning process among involved stakeholders.

The translation of the tool into an Excel form contributes to a convenient application. The tool in Excel form is a compact, electronically usable format with included explanations that facilitates a guided course through the different components of the tool. But even if no computers are available, the tool can easily be used on paper. After future adaptations of the tool (incorporating feedbacks of users), the electronic version of the tool can be further improved by making use of appropriate computer software.

The feasibility assessment tool can be further developed to an evaluation tool. In addition to the advantages in its current form, the feasibility assessment tool can relatively easily, by means of a few modifications, be further developed to a *project evaluation tool* to point out strength and weaknesses of an existing project and its operation. The tool can also potentially be used for failed AD projects to analyze and determine the causes of failure.

Uncertainty remains where the tool will be applied. Although generally perceived in a positive manner in Bahir Dar, an uncertainty remains if stakeholders, particularly initiators with a private sector background, will actually make use of this tool. There is a possibility that they might prefer a simple 'trial and error'-strategy. The tool is more likely to be used in institutional settings (smaller scale) than on municipal scale with a business approach like in Bahir Dar. Private companies might not be interested in including stakeholders' opinions due to fear that interference will delay the project or that their business ideas get stolen. Thus it is important to be aware of the underlying assumption that the initiator (lead party) actually wants to find out if the project is feasible.

8.4 AD project in Bahir Dar

The AD project in Bahir Dar is part of an integrated organic recycling centre for valorisation of biowaste, initiated by the private company Dream Light. The distinct strengths and weaknesses of the set-up as proposed in Bahir Dar are discussed below:

Dream Light has control over the whole supply chain (incl. substrate, AD process and product chain). One of the major strengths of the AD project as proposed in Bahir Dar is the fact that the main responsibility is in the hand of one organization (DL, Dream Light), that not only has a direct motivation to make the project work (financial reasons), but also has the possibilities to influence the activities along the AD chain. In other words, almost the whole supply chain is in the hands of Dream Light (substrate collection, transport, sorting, AD process and partly also use of the AD products).

Dream Light shows favourable business features. The high motivation, professionalism, willingness to take risks and well established network of Dream Light (DL) can surely be considered as a strong point within the proposed AD set-up. The fact that DL has used rather conservative assumptions for their financial analyses also speaks in favour of their competence and realistic project approach.

The idea of a diversified portfolio of waste recycling products (compost, biogas, bio-charcoal) is promising, but it has to be seen if all technologies work sufficiently well to generate high-quality products. The integrated recycling centre with its different technologies (composting, anaerobic digestion and bio-charcoal production) generates a diverse portfolio of products (compost as fertilizer and soil amendment, biogas used for bread baking, bio-charcoal for cooking). On one hand, this is an advantageous situation as it buffers the expectations towards one product alone to be financially successful. Different market segments are addressed (agriculture, food supply, cooking fuel) and the customers are to some extent even guaranteed (agreement with GIZ, Deutsche Gesellschaft für Internationale Zusammenarbeit for supply of charcoal briquettes; DL uses fertilizer on their own agricultural production sites). This clever marketing strategy results in a low socio-cultural risks of the project as no direct participation or behavioural change of the community is required.
On the other hand, a diverse portfolio of recycling technologies and products can also be disadvantageous, as it requires in-depth knowledge of a wide range of technologies. This research study has found that not all the required knowledge and skills are locally present yet; a fact that constitutes a major threat to the successful outcome of the entire project. In case of technological failures, it should be examined if implementation of technologies in sequence rather than in parallel will not lead to a better result.

The intended stepwise expansion of the organic recycling centre enables to first learn from mistakes and make improvements on small-scale before scaling-up. The strategy of DL to approach the organic recycling centre project in separate phases present a strong point: In the first phase, the AD, composting and briquetting can be tested on an experimental pilot-scale by using proven technologies with relatively low risk of failure. The experiences can then be analyzed and integrated into the up-scaling of the project.

The project receives considerable attention and thus attracts auxiliary support from other institutes. As the organic recycling centre is a pioneering project in East Africa, it receives considerable media attention, a fact which makes it additionally attractive for partners as it provides an interesting platform and conveys a positive image. Dream Light's great contribution in improving the cleanliness of Bahir Dar by providing adequate waste collection services is surely beneficial for the AD project because it guarantees the positive attitude and goodwill of the municipality and the inhabitants towards their activities.

The lack of involvement of partners with experience and competence in AD threatens the successful long-term operation of the project. One of the main weaknesses of the proposed technological set up of the AD project in Bahir Dar is the lack of institutional capacity for sound construction, operation and maintenance of the AD system. The company responsible for it (ThiGro Power) does not have sufficient experiences with systems on such a large scale. In addition, their base in Addis Ababa does not allow quick response to problems to be encountered. The Dutch Development Organization (SNV) could theoretically fill this capacity-gap due to its knowledge and experience with AD in Ethiopia and its office in Bahir Dar. However, although it is supportive of the project, SNV does not want to get directly involved in urban large-scale AD projects. Continued efforts are required to find ways of making use of locally available institutional capacity for the benefit of the project as well as for the competent partners.

The absence of a maintenance service strategy presents a major threat for the project. At the time when feasibility of the organic recycling centre was assessed, no clear maintenance strategy was developed yet. It is absolutely essential to set-up a schedule stating which activities have to be done when, how often and by whom and who is in charge of controlling if these maintenance and monitoring tasks have been done. The statement that a maintenance plan will eventually be written indicates that this highly relevant issue does not receive the attention it requires. A clear strategy should be an integrated part of any AD system set-up and its importance needs to be addressed and included in workshops and trainings right from the beginning.

No proper and thorough feasibility assessment has been done in advance. One weakness, which the AD project in Bahir Dar shares with many similar projects in developing countries is the fact that feasibility assessment done previous to the project start was limited to a techno-economic study done by the executing company ThiGro. This study is inaccurate, lacks important details, uses disputable assumptions and only presents a rough overview of the ideas to be implemented. The Environmental Impact Assessment (EIA) conducted by the Regional EPA also contains only limited amount of precise and thus useful information. The EIA presents and comments on AD technologies that are implemented in industrialized countries which are not suitable for the Ethiopian context. Some pictures and text parts of the EIA are simply copied from the internet without any relevant connection to the AD project as planned in Bahir Dar.

Several technical weaknesses were detected in the set-up of the project.

- ***Low biogas yield calculated by ThiGro***: Even after several requests for explanations, ThiGro Power was not able to comment on the derivation of the calculated biogas production. This can be interpreted by a lack of well-founded technical knowledge, conscious decision of not raising too high expectations or a simple arithmetical error.
- ***High ground water table on the site of the organic recycling centre***: This has led to considerable problems and delays. As the construction was done during rainy season, the ground water table was as high as to make a watertight digester impossible. It is not clear if the geotechnical conditions have not been assessed prior to construction or if the situation has been underestimated.
- ***The collapse of the slaps covering the compensation chamber***: A lack of experiences and capacity of the implementing company (ThiGro Power) became apparent when static considerations were disregarded. The collapsed slaps not only are an indication of poor design and workmanship but also raise concerns if all safety issues have been considered.
- ***Bad road conditions and long distance to agricultural field where digestate is used:*** Also not imposing a fundamental risk for the successful outcome of the AD project, the deteriorating conditions of the access road surely influences the financial suitability of the AD project negatively, as well as the 400km-transport of the digestate to the field of application. However, as these issues have been considered in the cost-benefit analysis (considerable maintenance costs of trucks), it can be assumed that the undertaking is still feasible.

The technological and operational weaknesses of the project in Bahir Dar threaten the feasibility, sustainability or in other words, the successful outcome of the entire AD project. Although the described issues seem small and negligible, they have to be taken seriously and seen as indication of either a lack of proper knowledge and skills, communication or insufficient preparation in the planning stage.

9 Conclusions and recommendations

The four objectives of this research were I) to get insight into the current solid waste system in Bahir Dar, and II) to provide a brief overview of AD technologies for biowaste and of the AD development in Ethiopia. Furthermore, the aim was III) to develop a methodology of assessing feasibility of AD technologies treating biowaste in developing countries and IV) to apply the developed tool on the project in Bahir Dar.
The conceptual framework for this thesis work was appropriate for the development of a feasibility assessment tool. The theoretical background of concepts (such as ISWM, sustainability and feasibility assessments) and technological knowledge about AD, combined with the gathered information of AD projects in developing countries and specifically in Ethiopia, enabled inclusion of all relevant issues that have to be considered when assessing feasibility of an AD system for urban anaerobic digestion.
The methodology included a literature study that served as a basis for developing a draft version of the tool and subsequently three months of fieldwork in Bahir Dar to apply, test and adapt the tool on-site.

9.1 SWM in Bahir Dar

Conclusion

The current solid waste management (SWM) in Bahir Dar is characterized by a successful public-private-partnership with the municipality and the private company Dream Light (DL) as very powerful stakeholders. The mutual dependency of these stakeholders became as evident as the fear of DL's monopolization (from the perspective of the municipality) and the fear of losing the municipal permission to collect and process municipal waste (from the perspective of DL). Further features of the current system encompass a collection rate of 71% (waste not segregated), and predominant waste disposal on an open dumpsite. The system includes different informal service providers, which are mostly active in small-scale re-use and recycling. The strongest driver has been protection of public health by providing proper collection services. It is only recently slowly shifted towards valorization of resources, whereas environmental protection concerns are foreseen to be tackled at a later stage.
Getting insight into the SWM before actually embarking on feasibility assessment of the proposed AD project has several distinct advantages: It enables understanding of the stakeholders, processes and flows in the current system - knowledge that is essential for feasibility assessment of AD, as it constitutes the context in which the project will take place. Knowledge of the characteristics, strengths and weaknesses of the current system is important when designing an AD chain.

Recommendations

Intensify efforts for source-segregation of organic waste: Efforts to encourage source-separation of organic waste should be intensified. While vague ideas already exist to distribute differently colored bags to households and institutions for separate collection of plastics, metals and organics, no concrete steps have yet been undertaken in this direction. A kebele (administrative unit in the city) should be chosen to start on a pilot-scale with involvement of local community organizations that support this development. It is further important to test a system of incentives (e.g. less payment fees for organic waste and recyclable inorganic materials). A system of source-separated waste enhances the waste generators' awareness about waste as a resource, offers a concrete way for their contribution and also facilitates recycling steps.

Start developing plans for up-grading of open dumpsite: As the risks for the environment and the health of the residents originating from an open dumpsite are manifold, it is important to support an evaluation on how the current disposal site can be improved. A consortium of interested and powerful stakeholders (among others municipality, Environmental Protection Agency and Dream Light) have to work together on finding appropriate solutions and funding possibilities to upgrade the dumpsite. It is important to not only work on reducing the amount of disposed waste, but also to search for improved ways of disposal, particularly in view of the rapid growth in population.

Institutionalize a regular meeting for exchange of SWM stakeholders: As there is no specific formal structure/platform (committee, regular meetings or specific person within the municipality) for communication of stakeholders, cooperation is difficult and exchange of information, ideas and opinions is deficient. A regular platform organized by the municipality would be favourably perceived by the other stakeholders and enhanced communication would help to achieve the two above mentioned points.

9.2 AD technologies for biowaste

Conclusion

Anaerobic digestion (AD) is a promising method for treatment of organic solid waste and has been applied on a worldwide scale. It is helpful to group the process chain of AD into three main components:

- ***Substrate chain*** (including waste generation, collection and transport)
- ***AD transformation process*** (incl. pre-treatment of substrate, transformation of waste into valuable products, post-treatment of products)
- ***Product chain*** (incl. distribution and utilization of biogas and digestate).

While in industrialized countries biogas is often generated on medium to large-scale for production of heat and steam, electricity, vehicle fuel and chemicals, in developing countries the gas is almost exclusively produced in small-scale systems and directly used for cooking, heating, light or refrigeration. It is important to put emphasis on digestate, the second product of AD as it can be used in agriculture as nutrient fertilizers and/or organic amendment. It is thus more appropriate to speak of a*naerobic digestion systems* rather than of *biogas systems*.

The choice of technology and scale depends among others on the climatic conditions and on the availability of substrate, water, technical knowledge, skills, materials, and financial resources. Although the report briefly describes the (high-tech and high-budget) AD technologies implemented in industrialized countries (5.3.1 AD technologies of biowaste in high-income countries), these technologies are of limited interest and suitability for developing countries due to different technical, financial, institutional, political and socio-cultural circumstances. Three types are predominately installed in developing countries: Fixed-dome underground digesters, floating-dome digesters and tube/bag digesters. Of these, the fixed dome underground system is considered to be most suitable for the developing country context as the technology is well known and widespread, cost-effective, the required components locally available and neither prone to corrosion nor easily damaged.

The Dutch Development Organization (SNV) has in 2007 started a National Biogas Programme in Ethiopia with the purpose of promoting rural domestic biogas systems using cattle dung as feedstock. In October 2011 roughly 1800 of these small-scale fixed dome underground digesters have been built. As a result of the trainings, workshops and construction activities of SNV, the institutional capacity for building, operating and maintaining fixed-dome digesters has been substantially increased in Ethiopia in the past years.

Recommendations

<u>Focus research on technologies suitable for developing countries</u>: Inclusion of advanced technologies from high-income countries in an AD overview for low-income countries raises the expectations to the same extend as the chances for failure do (when trying to implement these high-tech and -budget systems in developing countries). Thus analyse the AD technologies suitable for developing country context in more detail and adapt these proven technologies to the specific local circumstances.

<u>Develop a tool for dimensioning of the three main systems for developing countries</u> based on the availability of substrate, water and resources. Including a comparison of costs would be helpful for the decision-process of technology selection.

<u>Develop specific maintenance plans for each of these three technologies</u>: Based on experiences from existing projects, a clear maintenance plan should be worked out with pictorial support for illiterate people. Not only the regular maintenance tasks should be listed and explained, but also a template list created to be used for allocating the responsibilities.

<u>Find ways to involve SNV in supporting institutional AD systems in Ethiopia</u>: Considering the knowledge, experience and network of SNV in the field of AD, it would be a very capable partner for any institutional AD project. As discussed with the coordinator of the National Biogas Programme in Ethiopia, W. Boers, the developed feasibility assessment tool can contribute to pre-screening the projects that will be professionally guided and supervised by SNV.

Promote the benefits of the digestate as much as the benefits of the biogas. In times of rising prices for chemical fertilizers, depleted soils and limited resources (phosphorus), the significance of this AD by-product rises significantly. It is thus recommended to intensify the promotional efforts for rising awareness about the digestates' benefits, risks and mode of application.

Improve the visualization model for classification of AD technologies in a way that it constitutes an aid for distinguishing the characteristics of technologies used in developing countries. For this purpose, parameters such as availability and costs of required materials, level of needed construction skills and maintenance efforts etc. should be included. In contrast to the developed visualization model (5.3, p.46ff), which is more suitable for revealing the different characteristics of technologies in high-income countries, the new visualization model should rather be helpful to distinguish the different requirements for each model (e.g. CAMARTEC, GGC2047, Chinese model) of a single technology type (e.g. fixed dome).

9.3 Feasibility assessment tool and chosen methodology

Conclusions

The feasibility assessment tool facilitates systematic identification of strengths and weaknesses in terms of sustainability for proposed AD projects. Its approach and results create a sound basis for discussion of the project under assessment. The developed tool can be a valuable instrument for funding agencies to decide which project to support or to test the level of elaboration of a project proposal. It can also be useful for technical experts to systematically assess a project set-up. Moreover, it provides a tool for the initiating party to test the capacity of the company responsible for design, construction, start-up and instruction of the AD system and to select the most suitable project for the local circumstances or to adapt a selected project to increase its sustainability. The developed structure of the tool provides a standardized checklist, but it is recommended to adjust the list to the contextual situation.
The tool was well received by the stakeholders in Bahir Dar who also explicitly welcomed the workshop in order to openly exchange opinions and suggestions. Due to the valuable feedback of the stakeholders, some unclear formulations were detected and modified, and the assessment procedure simplified, while preserving its comprehensiveness and value.

Recommendations

Selectively distribute the tool to interested researchers in order to let them test it on different urban AD projects. This thesis can be downloaded for free from the Sandec website (www.sandec.ch). To test the susceptibility of the tool to subjectivity of the person conducting the feasibility assessment, one project should be assessed by different people (e.g. students) and the different results (scores) compared.

Encourage critical feedback and further refinements of the tool: The fieldwork confirmed that the tool is comprehensive and that it covers all relevant aspects. However, it would be interesting to hear what other researchers conclude when applying the tool. The author, currently working for Sandec/Eawag, welcomes any kind of comments (christian.lohri@eawag.ch). Feedbacks will be answered and incorporated in an advanced version thus leading to continuous improvement of the tool. Further refinement in terms of mathematical algorithm to quantify uncertainty could be conducted and is encouraged.

Summarize the tool in a compact, user-friendly version (including a manual), which can be printed in a limited edition and disseminated. At a later stage, when the tool has been further enhanced and proven its merits, an improved electronic layout and enhanced visualization method can be elaborated.

Modify the *feasibility assessment tool* to a *project evaluation tool* so that it can be used to evaluate already existing projects by pointing out strength and weaknesses of an existing project and its operation. The tool can also potentially be used for failed AD projects to analyze and determine the causes of failure.

Develop a methodology for an actual technology pre-selection based on questions answered about the local context (climatic conditions, available resources, institutional capacities etc.).

9.4 AD project in Bahir Dar

Conclusions

The chosen scale and AD technology in combination with the other organic recycling technologies (composting and charcoal briquetting) is feasible for the Bahir Dar context. Dream Light as main stakeholder has the support of other major stakeholders in the AD system because of its contribution to improve the SWM in Bahir Dar and also partly because DL's pioneering activities attracts considerable media attention. The designed value chain by DL seems promising as it allows direct control and intervention and minimizes risks of unpredictable unfavourable behaviour. It is advantageous that DL is working on professionalising its business structure.

The main threat for successful long-term operation of the integrated organic recycling centre and the AD project in particular, is the limited institutional capacity of the stakeholders who, until now, have been actively involved in the development process of the project.

Recommendations

- Actively seek the involvement of local AD experts (e.g. SNV) and make official agreements on how collaboration can be ensured so that both parties benefit from it. A trouble-shooting team that is locally and promptly available needs to be built up.

- Institutionalize collaboration with Bahir Dar University (BDU) and examine the possibilities of installing a small research container on the AD site. This would on one hand give BDU students the opportunity to learn methods of sampling and analyses on a real-life project; on the other hand would it provide important data to Dream Light and form part of a monitoring system on site.

- Document, collect and analyze the results and experiences from this first stage of the organic recycling project in order to enhance the learning effect and to increase the chances of success for the next (expansion) stages in the project.

- Apply the feasibility assessment tool to the expansion project in Bahir Dar. Dream Light and ThiGro Power plan to implement new AD technologies on a larger scale in the coming year. This provides an excellent opportunity to evaluate the proposed project by means of the feasibility assessment tool developed in this thesis and to make respective adjustments to increase its sustainability.

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Boers, Willem (2011): SNV, Head Coordinator of NBPE, Senior Biogas Advisor

Dejene, Kassa (2011): ThiGro Power, Manager

Fenzie, Melisachew (2011): Bureau of Environmental Protection, Land Administration & Use, Head of EPA

Gabbiye, Nigus (2011): Bahir Dar University, Associate Dean for Research and Postgraduate Studies

Getahun, Zelalem (2011): City Administration, Head of Sanitation, Beautification and Park Development

Hunegnaw, Getnet (2011): LEM Ethiopia, Head of Office; former EPA officer

Kada, Messele (2011): SNV, Technical Biogas Advisor

Ketaw, Tewdros (2011): Dream Light, Head of Field Operation, now Operation & Maintenance

Panse, Katharina (2011): IGNIS project, MSc student, Hochschule Zittau/Görlitz, Energie- & Umwelttechnik

Solomon, Tigist (2011): Dream Light, Accountant

Zeeman, Grietje (2011): WUR; Expert in Anaerobic Digestion

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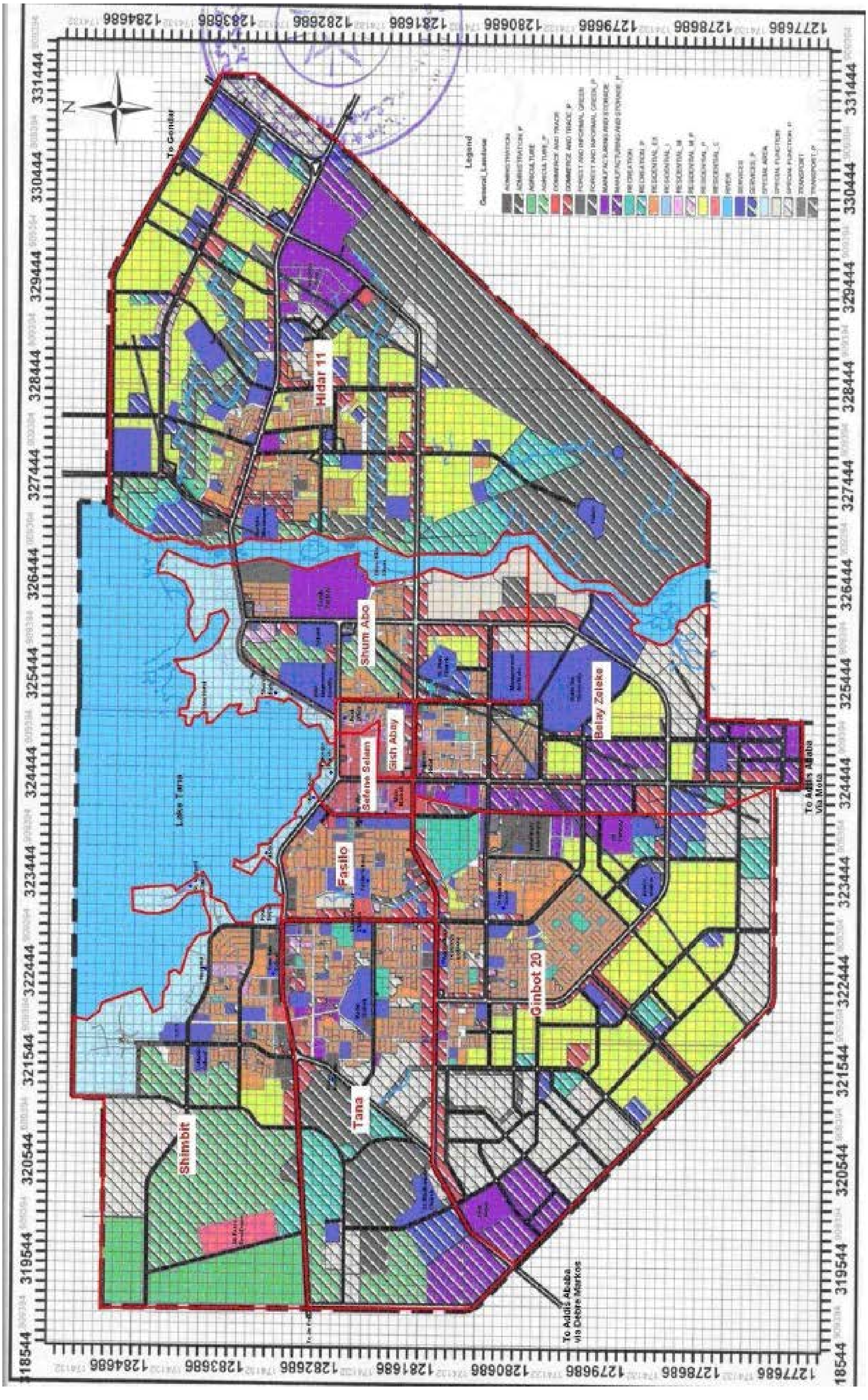
Appendices

Appendix I. Schedule of field work in Bahir Dar

Objectives	Research questions	Activities	W0 (W32) 12.8-14.8	W1 (W33) 15.8-21.8	W2 (W34) 22.8-28.8	W2 (W35) 29.8-4.9	W4 (W36) 5.9-11.9	W5 (W37) 12.9-18.9	W6 (W38) 19.9-25.9	W7 (W39) 26.9-2.10	W8 (W40) 3.10-9.10	W9 (W41) 10.10-16.10	W10 (W42) 17.10-23.10	W11 (W43) 24.10-30.10	W12 (W44) 31.10-6.11	W13 (W45) 7.11-13.11	W14 (W46) 14.11
Safe arrival and good start in BD		Find a guest house/pension/hotel for first 1-2 weeks	flight 12.8														
Get acclimatized with life in BD		Inquire about transportation, communication, accommodation, food, money, emergency contacts…															
Find suitable place for 3 months		Organize apartment, move there, get installed															
Prepare guidelines for meetings, visits, observation, data collection	1.a) 2.b)	Develop questionnaires															
Get accustomed with research & data collection in BD		Inquire about collaboration issues, hierarchies, codes of conduct, language etc.															
Get insight into SWM in BD	1.a)	Contact & meet stakeholders, visit landfill, veg. markets, transfer stations etc.															
Understand energy system in BD	2.b)	Contact & meet stakeholders in energy sector (cooking fuel, electricity, biogas…)															
Assess general feasibility for AD	3.a) b) c)	Collect relevant information, conduct general feasibility for AD in BD															
Get to know role, reputation, potential of AD in BD/Ethiopia	2.b)	Meet SNV and other biogas-related organizations, visit AD projects in Addis and BD															
Buffer week 1		*Continue meetings, discussions, data collection, writing*															
Start preparing feasibility assessment / workshop	3.a) b) c)	Invite stakeholders to workshop, organize location/ equipment, prepare criteria/indicators/ptt with aims/procedures															
Conduct constructive workshop	3.a) b) c)	WORKSHOP with stakeholders: Identify and agree with stakeholders on criteria/indicators, present scenarios, scores &weights -> performance matrix, inform about next steps									20 or 21.10				
Direct supervision by Ljiljana		Visit of Ljiljana to Bahir Dar											18-25.10				
Evaluate workshop & methodology	3.b)	Evt. conduct second short meeting to present results of workshops, evaluation sheet (methodology & workshop)															
Prepare conceptual AD design for BD	4.a) b)	Describe & visualize conceptual AD design based on workshop results, ask stakeholders for comments on this design															
Buffer week 2		*Continue meetings, discussions, data collection, writing*															
Round-up and return		Flight back to Switzerland															flight 11.11

Appendix II. Administrative map of Bahir Dar with nine urban kebeles
(UNEP, 2010a)



Appendix III. Domestic infrastructures in Bahir Dar

Housing units in Bahir Dar by source of drinking water (CSA, 2007; Amhara4)

		Source of drinking water						
BAHIR DAR	**All housing units**	**Tap inside the house**	**Tap in compound, private**	**Tap in compound, shared**	**Tap outside compound**	**Protected well or spring**	**Unprotect-ed well or spring**	**River/ lake/ pond**
Urban & rural	61'249	1'521	8'873	23'284	15'3384	3'479	2'704	6'050
Urban	51'744	1'368	8'771	23'116	13'444	1'330	1'213	2'502
Rural	9'505	153	102	168	1'894	2'149	1'491	3'548

Housing units of Bahir Dar by type of toilet facilities (CSA, 2007; Amhara4)

		Type of toilet facility						
BAHIR DAR	**All housing units**	**No toilet facility**	**Flush toilet, private**	**Flush toilet, shared**	**VIP latrine, private**	**VIP latrine, shared**	**Pit latrine, private**	**Pit latrine, shared**
Urban & rural	61'249	26'661	2'821	4'532	1'420	3'559	4'226	18'032
Urban	51'744	18'115	2'607	4'435	1'364	3'518	3'996	17'710
Rural	9'505	8'546	214	97	56	41	230	322

Housing units of urban Bahir Dar by type of cooking fuel (CSA, 2007; Amhara4)

		Type of fuel for cooking							
BAHIR DAR Special zone	**All housing units**	**Electricity**	**Gas**	**Kero-sene**	**Charcoal**	**Fire-wood**	**Dung**	**Biogas**	**Other**
Urban	51'744	1'585	614	13'635	38'015	42'461	20'696	322	2'172

Housing units of urban Bahir Dar by type of lighting (CSA, 2007; Amhara4)

		Type of lighting								
BD Special zone	**All housing units**	**Electri-city/meter private**	**Electri-city/meter shared**	**Electricity from generator (no meter)**	**Solar energy**	**Lan-tern**	**Bio gas**	**Lamps**	**Candle/ Wax candle**	**Fire wood**
Urban	51'744	10'279	35'131	559	-	81	15	5'463	91	126

Appendix IV. General questionnaire used as a guidelines for the assessment of SWM in BD

Analytical framework: combination of UN-Habitat methodology (2010) and ISWM concept (2001)

1. <u>WHY? (Development drivers and stage of modernization)</u>

1.1 Driver 1: Public health (→ Waste collection)

- When, how and why did waste collection start in Bahir Dar? (Specific health crisis in the past which led to citizen pressure for starting or upgrading MSWM services? Specific campaigns on health issues related to SWM that led to start or upgrade of waste collection services?)
- Ongoing activities/projects on improvement of SWM related to public health?

1.2 Driver 2: Environment (→ Disposal)

- When, how and why was the location for dumpsite designated?
- Ongoing activities/projects on improvement of SWM related to environmental concerns?

1.3 Driver 3: Resource value (→ Resource recovery)

- When, how and why did reuse/recycling/composting start?
- Ongoing activities/projects on improvement of SWM related to resource recovery?

1.4 Other drivers

- Any activities/developments (e.g. tourism, public awareness, institutional changes etc.) pointing in direction of additional drivers?

1.5 Summary of development drivers and modernization
- *Overall state of modernization?*
- *Main current focus of municipal government?*
- *Main current focus of other stakeholders?*

2 WHO? (Stakeholders)

2.1 SWM-Stakeholders (relations and responsibilities)
- Who are the stakeholders in waste management in the city? (Who has an interest in waste management or is affected by it?)
- What type(s) of activities do these stakeholders carry out?
- What power and interest in the current SWM system does each stakeholder have?
- Does the municipality cooperate with these stakeholders? If so, in what way?
- How do they communicate with each other? Is there a structure/platform (committee, regular meetings, specific person inside the municipality) for communicating with other stakeholders?
- Is there a complaint mechanism in the municipality for the general public (to complain about missed collection, illegal dumping etc)?
- Is this complaint mechanism functioning well?
- Result of user satisfaction survey
- Is waste management working with or against other urban systems? If so, in which ways?
- Is there equity among service providers – large and small, formal and informal – in terms of a fair share of economic opportunities for providing the service or valorizing materials?
- Do other stakeholders cooperate with each other (without municipality participation)? If so, in what way?

2.2 Summary of stakeholder analysis
- *How is the current SWM organized in Bahir Dar (Organogram or other type of visualization for relations/responsibilities, power/interest-Matrix)?*

3 WHAT? (Basic description of physical MSW system components and flows)

3.1 Generation (+ Prevention; Def: Prevention of waste creation in product design and packaging)
- Description of different current waste generation (sources and streams) and prevention activities
- Official definition by municipal authorities for MSW, residential, commercial, hazardous waste and organics (*check soil & ash issue*)
- Waste quantities (+ seasonal variations incl. reasons, extents and consequences of changes)
- Dry matter (TS) and organic content (VS) of organic waste

3.2 Collection &Transport
- Description of different currently practiced collection and transport
- Inventory of collection staff and equipment
- Means of primary collection (push carts, vehicles etc.), from households/institutions/commercial clients to collection points (if any) otherwise to transfer station (if any) or directly to disposal site?
- Means of secondary collection and transport from collection point (if any) to transfer station (if any) or directly to disposal site?
- Number of official collection points & transfer stations in the city? Number of unofficial (but commonly accepted) collection points?
- Number of litter bins in commercial areas (size and material), bins filled at the time of collection?
- Vehicle productivity (amount of waste collected per route and per time unit)
- Vehicles availability (average % downtime of vehicles)
- Frequency/intervals of collection from households, institutions, commercial clients, litter bins, collection points?
- How much waste is collected from each generator group (absolute number and as a % of total amount generated)*?*
- Separate collection of hazardous waste?
- Collection of source separated waste (absolute number and as a % of total amount collected)?
- Collection coverage rate (as % of total population that receive waste collection service, ratio between offered services/accepted services)
- Sweeping coverage (absolute number and as % of total km; which are non-swept areas?)
- Areas not receiving collection service and sweeping (which & why?)

3.3 Treatment & Disposal

- Description of different currently practiced treatment and disposal
- How is disposal operated? (some form of control of incoming waste at the gate, amounts measured and recorded, any compaction applied, any daily cover applied on the waste disposed of)?
- Engineered controls applied at the disposal site (bottom liner, leachate collection and removal system (LCRS), landfill gas extraction and utilization system)?
- Disposal rate (absolute number and as % of waste collected which is disposed of in a sanitary landfill and in dumpsite)
- Amount of uncontrolled/illegal dumping (absolute number and as % of total waste generated)
- Means of hazardous waste disposal
- Are there any waste pickers working at the site? How many? Every day of the week? In all seasons?

3.4 Resource recovery

- Description of different currently practiced resource recovery, including traditional reuse (Def. Reuse: Use of waste materials in the same form without significant transformation)
- Which wastes are diverted from disposal (valorized) from household, institutions, commercial areas before entering the SWM system? (absolute number and as % of total waste generated)
- Which wastes are diverted from disposal (valorized) by formal and informal activities after having entered the SWM system? (absolute number and as % of total waste generated)
- Which materials are recovered for recycling by whom?
- How many operations (how many types of stakeholders) are involved from waste generator to the material end user?
- Where do these products end up and what are their final uses?
- What are the monetary values of these products?
- Total waste recycled (absolute number and as % of total waste generation)
- Total organic waste that goes to agricultural chain (absolute number and as % of total diverted/valorized)

1.5 Summary of physical system components (visualized in PFD)

- *What system elements are included in municipal waste management at present?*
- *Which services are provided (and by whom, making use of the results from chapter 1 "Who?")?*
- *What materials flow in which quantities through each of the following process steps: Generation, Reuse, Waste Collection, Separate collection for recycling, Separate collection of organic waste for valorization (in agricultural or other value chain), Transfer, Processing/Treatment, Incineration, Disposal)?*

→ *Visualization through Process Flow Diagram*

4. HOW? (Performance/sustainability aspects)

1.1 Technical-functionality aspects

- Which system components are locally available, which ones are only nationally available and which ones only internationally?

1.2 Environmental

- Do any physical system components cause environmental resource depletion, pollution or degradation? In particular, do they:
    - Use non-renewable substances extracted from the Earth's crust and thereby contribute to the progressive build-up of those (e.g. Fossil fuels, heavy metals etc)?
    - Use chemicals and compounds produced by society and thereby contributing to the progressive build-up of those (e.g. fossil-fuel-based products leading to environmental pollution [exceeding the legal standards if existing])?
    - Cause physical degradation and destruction of nature and natural processes (e.g. over-harvesting of forests, paving over critical wildlife habitats etc)?

1.3 Socio-cultural aspects

- How is the public level of awareness about (the necessity of sound) SW in general?
- What is the level of participation in the current SWM practices (waste separation, transport)
- Why is the waste not being collected or swept in certain areas?
- Do women have a recognized influence on waste management? Have they ever been asked their opinion separately from men?

- Are the provided structures/platforms for communication between stakeholders being used? If not, what are the reasons?
- Is the complaint mechanism provided by the municipality for the general public being used? If not, what are the reasons?
- Do elements of the current SWM system lead to conditions that undermine people's capacity to meet their basic human needs (e.g. unsafe working environment, exclusion of services, salaries insufficient to make a living etc) now or in the future?

4.4 Financial-economic aspects

- Does the municipality have authority to raise its own funds for waste management (through fees/taxes)?
- Does waste management have its own budget lines? Are these guaranteed (only to be used for waste management, e.g. collection fees only for SWM), contingent (budget items only funded when enough fees are collected) or in competition with other functions?
- Are costs analyzed before fees are set?
- What costs are included, what % of the costs through waste collection fees and taxes are recovered? If not all costs are recovered, where does the rest come from?
- Investment and operational cost of waste management
- What are the current fees charged to households and other waste generators, specified per generator?
- Households/commercial clients/institutions paying for services (as % of those getting the service)?
- Affordability (solid waste fee as % of family income per month or per year)
- Fee collection/payment rate, per generator

4.5 Institutional aspects

- Does the municipality have the authority to contract private enterprises and how easy are the conditions for contracting of small-scale enterprises and community-based organizations?
- Are the outsourced municipal waste collection services defined, supervised and controlled by the municipalities? Is there adequate institutional capacity to carry out these tasks? In other words, do the staff know how to make a good contract (one which will lead to a good service) and how to monitor the performance of the private company (confirming that the company is doing what is stipulated in the contract)?
- How are the working conditions for waste management workers (uniforms, gloves, low loading height, extra allowance for risks incurred, health insurance, health services)?

4.6 Policy/Legal/Political aspects

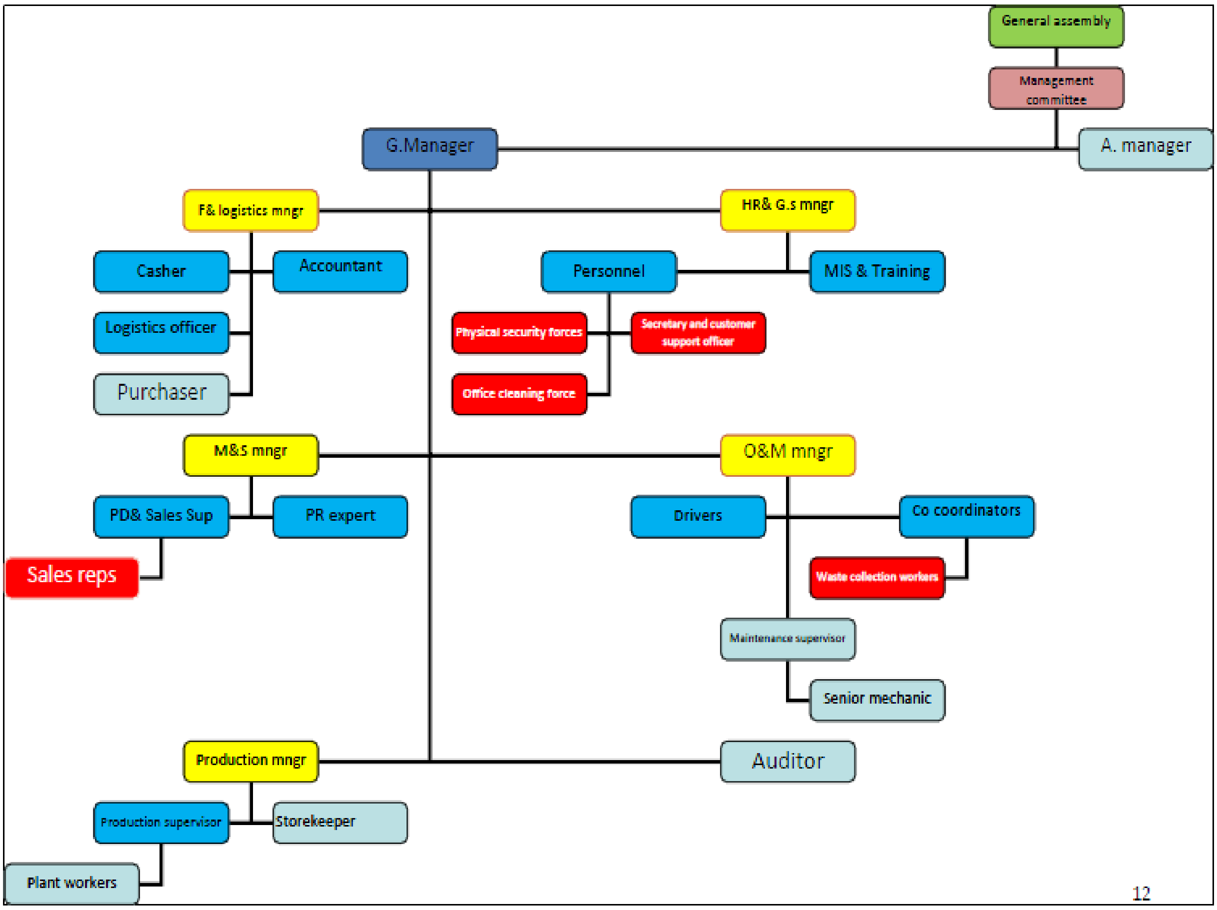
- Is there a clear and transparent policy framework for the planning and implementation of WM practices?
- Are there any sustained policy commitments/regulations to sustainable solid waste management (waste prevention, safe reuse and recycling)?
- Are there policies, budgets and activities for environmental awareness-raising?
- How coherent and autonomous is the solid waste management functioning within the city?
- Is solid waste management the responsibility of one department or are tasks divided over separated departments?
- Are all waste management, recycling and composting functions under a single municipal jurisdiction?
- Are there legal documents which oblige the municipality to engage in the cooperation between municipality and other stakeholders? Are there legal documents which prescribe the structure/platform of cooperation, and the situations where this cooperation has to take place? For example:
    - Do clients have influence on the fee structures and service levels via some form of public participation (discussion in local elected councils, public meeting, social survey)?
    - Do citizens have a say when SWM plans are made?
    - Do citizens have a say when new facilities are sited?
- Are there policies to support or control the informal sectors?

4.7 Summary of sustainability aspects

- *How overall sustainable is the current SWM in BD?*
- *How can the SWM in BD be improved in order to attain full inclusivity of stakeholders, financial sustainability, sound institutions/proactive policies and environmentally sound technologies/operations?*
- *Are initiated activities moving towards a sustainable improvement of SWM in BD?*

Appendix V. Company structure of Dream Light PLC (October 2011)

(Source: Dream Light Strategic Plan, 2011)



Appendix VI. SWM in Bahir Dar: Power-interest evaluation by stakeholders

Stakeholders were asked to give rates from 1-10 (1: low power/interest; 10: high power/interest)

	Alemnew DL		Getahun CA		Fenzie EPA		Biazn FfE		Birhanu BDU		**Average**	
Stakeholder	***Pow.***	***Int.***	***Pow.***	***Int.***	***Pow.***	***Int.***	***Pow.***	***Int.***	***Pow.***	***Int.***	***Pow.***	***Int.***
City Administration	10	7	9	6	10	4	10	9	9	5	**9.6**	**6.2**
Regional B.O.E.P.L.A.U	8	5	8	8	8	9	5	9	6	5	**7.0**	**7.2**
Regional Health Bureau	7	5	7	7	5	5	7	8	7	7	**6.6**	**6.4**
Regional Government	7	3	4	6	4	7	7	7	4	5	**5.2**	**5.8**
UNDP	7	7	7	7	7	8	6	8	4	5	**6.2**	**7**
Dream Light	6	10	9	10	3	10	9	10	7	9	**6.8**	**9.8**
Green Dream	2	8	6	9	2	9	6	7	3	8	**3.8**	**8.2**
Million & Friends	4	7	6	8	2	6	6	7	3	8	**4.2**	**7.2**
Forum for Environment	1	9	4	6	3	10	3	9	8	8	**3.8**	**8.4**
BD University	1	5	6	6	7	3	5	7	4	8	**4.6**	**5.8**
Households	5	7	6	9	2	8	4	10	4	5	**4.2**	**7.8**
Commercials	5	9	6	9	4	8	5	7	4	6	**4.8**	**7.8**
Institutions	4	4	6	9	4	8	6	8	4	6	**4.8**	**7.0**
Informal recyclers	1	9	3	5	1	5	1	8	2	6	**1.6**	**6.6**

Appendix VII. Feasibility Assessment Tool (Excel template)

Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project (proposal) name:

Date:

1. WHY? (Drivers and motivations)

1.1 Motivation behind the AD project

Motivations of:

- Initator:
- Funding agency:
- Local authority:
- Others:

1.2 Social driver (public awareness or pressure form other stakeholders)

Pressure from stakeholder?

If so,

- When?
- How?
- By whom?
- Why specifially

Other ongoing activities?

1.3 Environmental driver (Resource recovery for environmental sustainability)

Recovery of resources?

If so,

- When?
- How?
- By whom?
- Why specifially

Other ongoing activities?

1.4 Economic driver (Financial considerations → Valorisation of resources)

Valorisation of resources?

- When?
- How?
- By whom?
- Why specifially

Embedded in other activities?

1.5 Other drivers

Other activities as main reasons for start of AD project?

Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project (proposal) name:	
Date:	

2. WHO? (Stakeholders in AD system)

2.1	List of all AD stakeholders	Role	Power *High* *Medium* *Low*	Interest *Supportive* *Neutral* *Disruptive*	Individual driver	Means of intervention

To ensure that no relevant stakeholder is forgotten, please make sure that the following groups are included:

1. Funding agency
2. Governmental authorities
3. Waste generators
4. Design and installation specialists
5. (Future) operation & maintenance staff
6. End-users of AD products
7. Legislator and enforcement agencies
8. Research institutions
9. National and international NGOs
10. Site residents (if any)

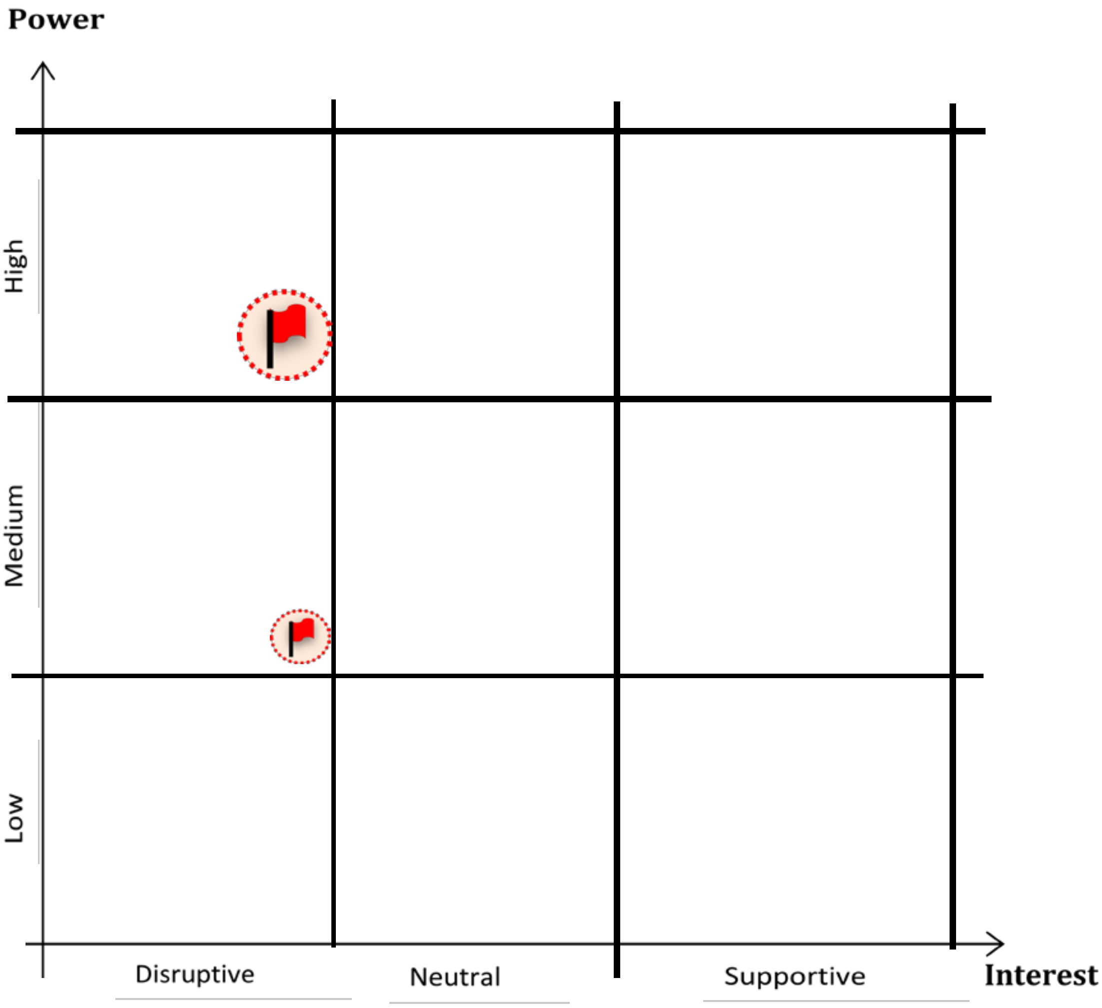
Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project (proposal) name:

Date:

2.2 Power-interest Matrix

Fill in the power and interest results from above of all AD stakeholders in the Power-Interest Matrix underneath.



Checking point:
Are there stakeholders with medium or high power that show a disruptive interest in the AD project? --> If yes, red flag

In such case, what kind of interventions are necessary to reduce the disruptive interest ot these stakeholders?

Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project (proposal) name:	
Date:	

3. WHAT? (Physical components & flows of AD chain)

3.1 Substrate chain

Substrate quantities (+ seasonal variations)	
Dry matter (TS) and organic content (VS) of different organic substrate groups	
Description of proposed collection of AD substrates and transport (incl. distance) to AD site	
Inventory of staff and equipment for substrate collection	
Means of primary collection/transport from source to collection points (if any) or directly to AD site?	
Means of secondary collection/ transport from collection point (if any) directly to AD site?	
Frequency/intervals of substrate collection from households, institutions, commercial clients, collection points and transport to AD site?	

3.2 AD technology (including pre- and post-treatment)

Description of the proposed AD technology	
Description of location and required space	
Range of substrate amount needed for sound operation	
Range of daily substrate quality needed for sound operation	
Required daily water quantity	
Proposed pre-treatment steps for substrate	
Energy requirements for operation of AD system	
Expected gas yield (m3), quality/purity (CH4, H2S) and energy value of biogas (kWh/m3)	
Expected VS removal	
Expected digestate quality	
Proposed control devices applied at the AD site	
Proposed post-treatment steps for biogas	
Proposed post-treatment steps for digestate	

Checking point: Proven performance record?
If not: Red flag (i.e. pilot tests are required first)

Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project (proposal) name:	
Date:	

3.3	**Product chain**	
	Proposed distribution of biogas (incl. distance from AD plant to biogas user)	
	Proposed use of biogas	
	Proposed user(s) of biogas	
	Proposed distribution of digestate (incl. distance from AD plant to digestate user)	
	Proposed use of digestate	
	Proposed user(s) of digestate	

3.4 Summary of physical system components: Visualized AD system

What system components and flows are included in the proposed AD system?
Based on the answers given above, draw a process flow diagram for visualization of the AD chain

Appendix VIII. Feasibility Assessment results of AD project in Bahir Dar

Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

AD project name:	AD project in Bahir Dar (Dream Light's Organic Recycling Centre)
Date:	October 2011

4. HOW? (Aspects of enabling environment, sustainability)

4.1 TECHNOLOGICAL-OPERATIONAL feasibility criteria					
4.1.1. Substrate chain		Organic waste quantity			
	a	Availability of organic waste			x
	b	Variation in waste quantities			x
	c	Measurement of daily input quantity	x		
		Organic waste quality			
	d	Separation and pre-treatment of substrate		x	
	e	Variation in waste quality		x	
		Water			
	f	Availability & accessibility of water			x
		Distance from generation to AD plant			
	g	Distance		x	
	h	Accessibility of AD system		x	
		Average score of substrate chain		2.5	

4.1.2. AD Technology		Space availability			
	a	Space for storage/transfer stations	x		
	b	Space for AD system plus working area			x
		Material availability			
	c	For construction		x	
	d	For start-up			x
	e	For maintenance & monitoring		x	
	f	For use of AD products		x	
		Performance of AD technology			
	g	Climatic conditions		x	
	h	Process stability		x	
	i	Process efficiency		x	
	j	Designed biogas yield	x		
	k	Geotechnical conditions	x		
	l	Clear maintenance strategy	x		
	m	Essential control devices			x
		Flexibility & robustness of AD technology			
	n	To changes in feedstock		x	
	o	To changes in climatic conditions		x	
	p	To electricity black-outs			x
	q	Lifespan of digester			x
	r	Lifespan of most sensitive parts		x	
		Average score of AD technology		0.6	
4.1.3. Product chain		Biogas quality			
	a	Biogas quality			x
	b	Post-treatment of biogas			x
	c	Biogas quality variation			x
	d	Distance from AD site to biogas user			x
		Digestate quality for planned utilization			
	e	Digestate quality			x
	f	Post-treatment of digestate			x
	g	Quality variation			x
	h	Distance from AD site to digestate user	x		
		Average score of substrate chain		7.5	
		Average score of technological-operation feasibility		**3.5**	

		4.2 ENVIRONMENTAL feasibility criteria			
4.2.1		Use of non-renewable substances			
	a	In collection & transport		x	
	b	In construction and operation		x	
	c	In distribution/transport and utilization		x	
		Average score of use of non-renewables		0.0	
		Use of chemicals			
	d	In collection and transport		x	
	e	In construction and operation		x	
	f	In distribution/transport and utilization		x	
		Average score of use of chemicals		0.0	
		Degradation and destruction of nature			
	f	Degradation and destruction of nature			x
		Average score of natural degradation		10.0	
		Average score of envrironmental feasibility		**3.3**	

		4.3 FINANCIAL-ECONOMIC feasibility criteria			
4.3.1	a	Funding situation		x	
	b	Market situation		x	
	c	Cost-benefit analysis			x
	d	Net Present Value			x
		Average score of financial-economic feasibility	**5.0**		

		4.4 SOCIO-CULTURAL feasibility criteria			
4.4.1		Acceptance			
	a	Handling of AD substrates		x	
	b	AD technologies		x	
	c	AD products (biogas & digestate)		x	
		Average score of acceptance	0.0		
4.4.2		Willingness to change behavior			
	a	Source separation of waste			
	b	Biogas for cooking/other planned purpose			
	c	Digestate as fertilizer			
		Average score of willingness			
4.4.3		Conditions that increase people's capacities			
	a	Employment generation			x
	b	Paying fair salaries			x
	c	Safe working conditions		x	
	d	Equal opportunity of inclusion			x
	e	Poverty reduction			x
	f	Distribution of burden & benefits (econ.,soc.,env.)		x	
		Average score of conditions that increase capacities	6.7		
		Average score of socio-cultural feasibility	**3.3**		

		4.5 INSTITUTIONAL feasibility criteria			
4.5.1		Institutional capacity			
	a	To design, supply materials, build & operate AD plant	x		
	b	To provide training and education	x		
	c	To carry out process monitoring & trouble-shooting	x		
	d	Physical spaces for education, training & workshops			x
		Average score of institutional capacity	-5.0		
4.5.2		Stakeholder cooperation			
	a	Cooperation in the AD chain			x
	b	Clarity of responsibilities		x	
	c	Possibilities to motivate stakeholders			x
		Average score of institutional capacity	6.7		
		Average score of institutional feasibility	**0.8**		

		4.6 POLICY & LEGAL feasibility criteria			
4.6.1		AD policies			
	a	Current policies		x	
	b	Current legislation, standards and regulations		x	
	c	Current enforcement law practices			x
	d	Prospect of supportive policies		x	
	e	Prospect of supportive legislation, standards, reg.		x	
		Average score of policy & legal capacity	2.0		
		Average score of policy & legal feasibility	**2.0**		

		4.7 UNCERTAINTY FACTORS (Risks)	Factor 0.5	Factor 1
4.7.1		**Technological-operational uncertainties**		
	a	Risk that substrate quantity and quality will not be delivered		x
	b	Risk that water quantity and quality will not be delivered		x
	c	Risk that material for construction will not be delivered		x
	d	Risk that AD technology will not perform as designed	x	
	e	Risk that maintenance_will not be done	x	
	f	Risk that location of the AD system will not be suitable		x
	g	Risk that technological-operational assessment is not reliable	x	
		Average factor of technological-operational uncertainty	**0.79**	
4.7.2		**Environmental uncertainties**		
	a	Risk that environmental assessment is not reliable		x
		Average factor of environmental uncertainty	**1.00**	
4.7.3		**Financial-economic uncertainties**		
	a	Risk that loans for investment will not be received		x
	b	Risk that cost of construction will be higher than planned		x
	c	Risk that cost of operation will be higher than planned		x
	d	Risk that demand for biogas will decrease		x
	e	Risk that demand for digestate will decrease		x
	f	Risk that customers will refuse to buy the AD products		x
	g	Risk that the distribution of AD products will not function		x
	h	Risk that financial-economic assessment is not reliable	x	
		Average factor of financial-economic uncertainty	**0.94**	
4.7.4		**Socio-cultural uncertainties**		
	a	Risk that acceptance of AD technology and products will worsen		x
	b	Risk that required behaviour will not be attained		x
	c	Risk that conditions created by AD will be worse than now		x
	d	Risk that socio-cultural assessment is not reliable	x	
		Average factor of socio-cultural uncertainty	**0.88**	
4.7.5		**Institutional uncertainties**		
	a	Risk that institutional capacities will worsen		x
	b	Risk that stakeholder cooperation will worsen		x
	c	Risk that institutional assessment is not reliable		x
		Average factor of institutional uncertainty	**1.00**	
4.7.6		**Policy & legal uncertainties**		
	a	Risk that disruptive policies regarding AD will be established		x
	b	Risk that disruptive legislation, standards will be enacted		x
	c	Risk that policy & legal assessment is not reliable	x	
		Average factor of policy & legal uncertainty	**0.83**	

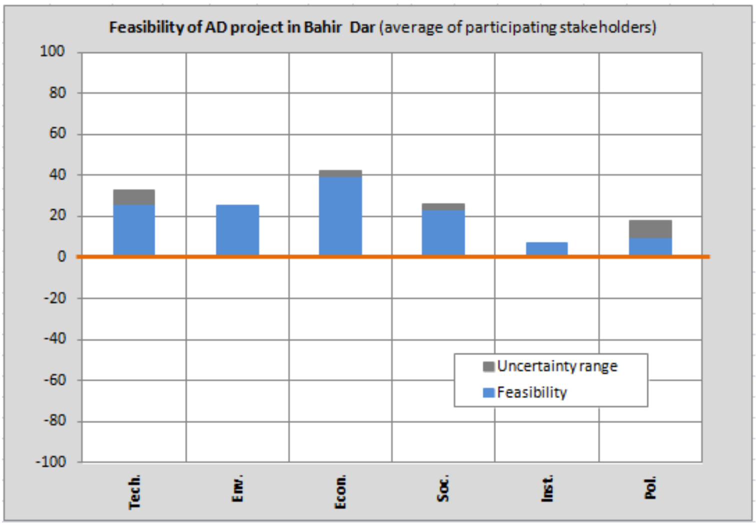
Feasibility Assessment Tool for Urban Anaerobic Digestion in Developing Countries

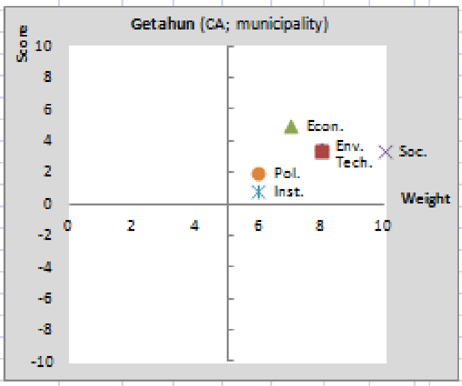
AD project (proposal) name: AD project in Bahir Dar (Dream Light's Organic Recycling Centre)
Date: October 2011

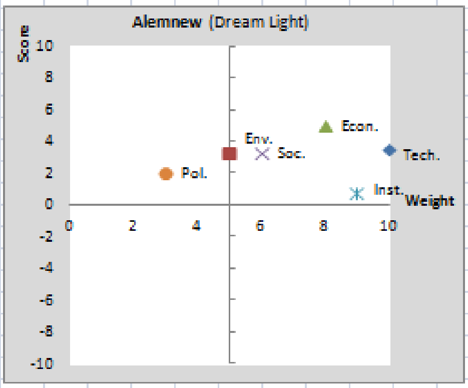
4. HOW? (Aspects of enabling environment, sustainability)

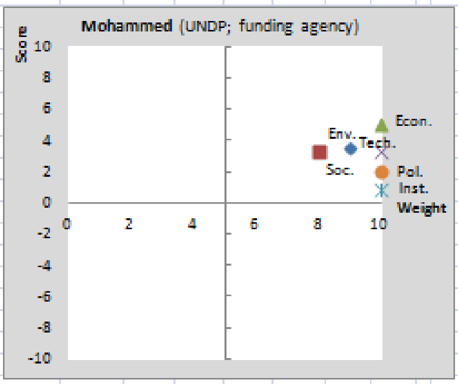
Stakeholder	Organization	Tech.	Env.	Econ.	Soc.	Inst.	Pol.
Getahun	CA	8	8	7	10	6	6
Alemnew	DL	10	5	8	6	9	3
Kada	SNV	10	5	9	5	8	3
Mohammed	UNDP	9	8	10	10	10	10
Gabbiye	BDU	10	8	7	9	10	6
Abrha	DL	10	4	10	9	10	5
Birhanu	BoH	8	10	7	10	9	9
Metalian	BoUD	9	8	9	9	10	7
Fenzie	EPA	9	9	9	7	5	5
Desta	ARARI	10	8	8	6	9	5
Abera	SNV	10	8	7	8	9	6
Alemayehu	BDU	9	10	10	6	9	7
	Average	9.3	7.6	8.4	7.9	8.7	6.0

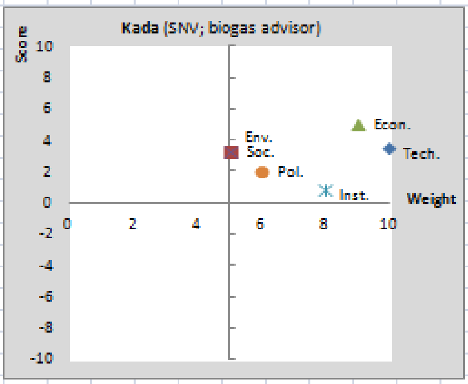
	Technological-operational			Environmental			Financial-economic			Socio-cultural			Institutional			Policy & legal		
Average scores	3.5			3.3			5.0			3.3			0.8			2.0		
Uncertainty factors	0.79			1.00			0.94			0.88			1.00			0.83		
Stakeholder	max	min	diff	max	min	diff	max	min	diff	max	min	diff	max	min	diff	max	min	diff
Getahun	28	22	6	27	27	0	35	33	2	33	29	4	5	5	0	12	10	8
Alemnew	35	28	8	17	17	0	40	38	3	20	18	3	8	8	0	6	5	4
Kada	35	28	8	13	13	0	50	47	3	30	26	4	8	8	0	10	8	7
Mohammed	35	28	8	17	17	0	45	42	3	17	15	2	7	7	0	6	5	4
Gabbiye	35	28	8	27	27	0	35	33	2	30	26	4	8	8	0	12	10	8
Abrha	32	25	7	27	27	0	50	47	3	33	29	4	8	8	0	20	17	13
Birhanu	28	22	6	33	33	0	35	33	2	33	29	4	8	8	0	18	15	12
Metalian	32	25	7	27	27	0	45	42	3	30	26	4	8	8	0	14	12	9
Fenzie	32	25	7	30	30	0	45	42	3	23	20	3	4	4	0	10	8	7
Desta	35	28	8	27	27	0	40	38	3	20	18	3	8	8	0	10	8	7
Abera	35	28	8	27	27	0	35	33	2	27	23	3	8	8	0	12	10	8
Alemayehu	32	25	7	33	33	0	50	47	3	20	18	3	8	8	0	14	12	9
Average	33	26	7	25	25	0	42	39	3	26	23	3	7	7	0	12	10	8



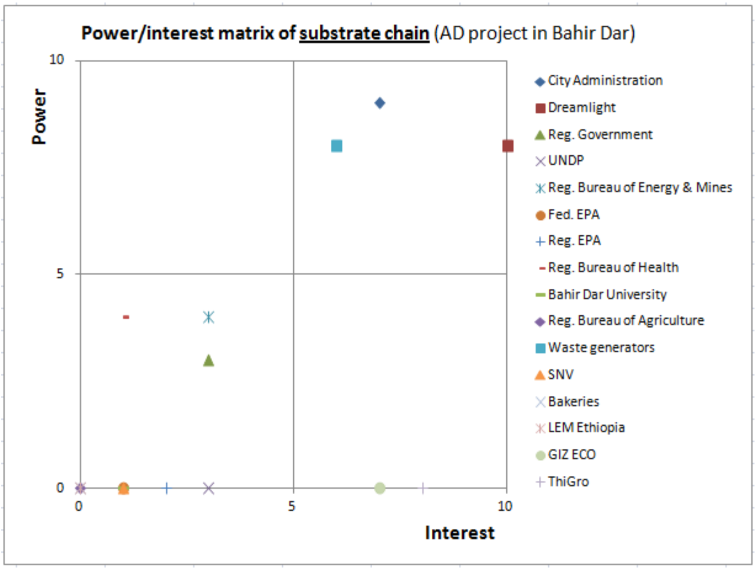


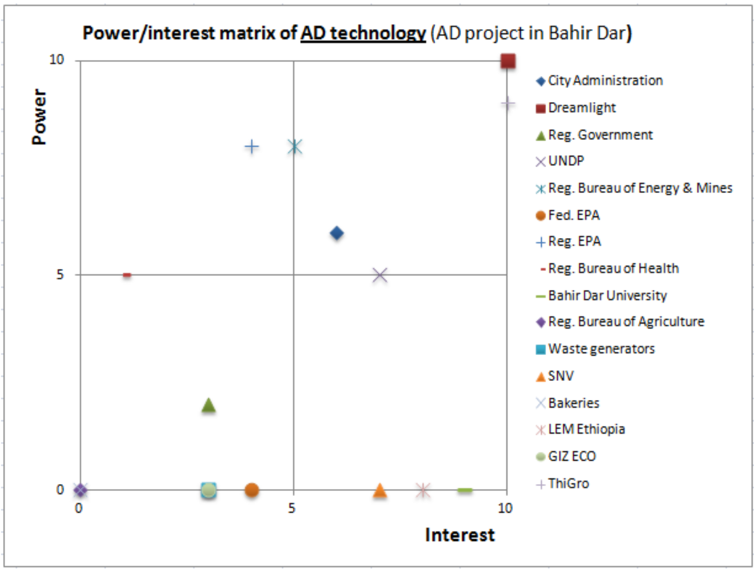


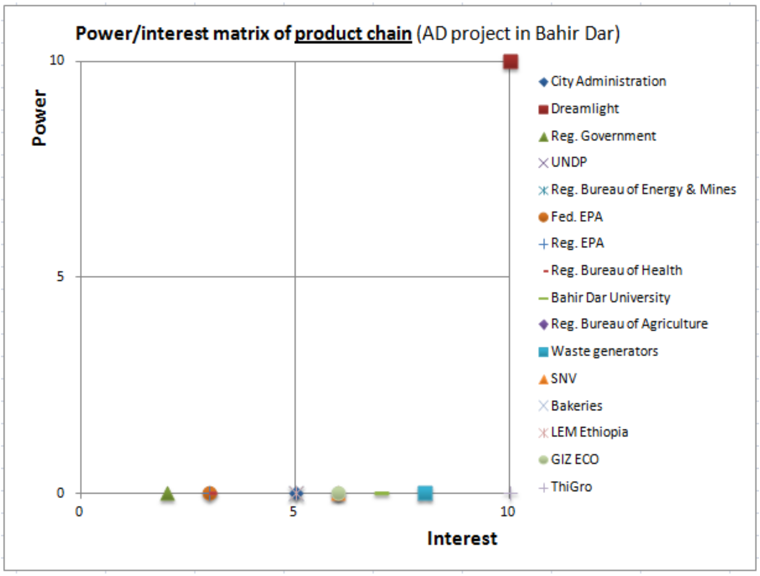




Appendix IX. Detailed power-interest matrix for AD system in Bahir Dar







Appendix X. Modified sheet for stakeholders to assign weights to main feasibility criteria

Modified version including comments derived from stakeholder workshop of 25 October 2011

NAME of stakeholder: ____

<u>Question</u>:

In your opinion, how important is this criterion for the success of an anaerobic digestion (AD) project?

Please give weights between 1 and 10 to the following six main feasibility criteria

1 – Not important at all
10 - Essentially important

Feasibility criteria	*Explanation*	*Weight (1-10)*
Technical-operational	- Availability (quantity and quality) of organic waste and water, accessibility of AD system (road conditions, distance between waste generation and AD system) - Availability of space and material for construction and operation of AD system; performance, flexibility and robustness of technology - Biogas and digestate quality and distance between AD system and users of AD products	________
Environmental	- Use of non-renewable materials (in substrate chain, construction and operation, products distribution and use) leading to increased concentration/contamination in one of the environmental compartments (water, soil, air) - Use of chemical and compounds produced by society (in substrate chain, construction and operation, products distribution and use) leading to increased concentration/contamination in one of the environmental compartments (water, soil, air) - Physical degradation and destruction of nature and natural processes as a result of the AD technology	________
Financial-economic	- Economic background (funding conditions incl. payback period & interest rate, financial incentives, CDM) - Market situation (e.g. demand, price, promotion) - Cost-benefit analysis	________
Socio-cultural	- Acceptance (of substrate handling, use of biogas/digestate) - Willingness to change behaviour (waste sorting, use of biogas for cooking and digestate as fertilizer) - Conditions that increase people's capacities to meet their needs (employment generation, fair salaries, safe working conditions, equal opportunity for inclusion, distribution of burden and benefits)	________
Institutional	- Institutional capacity (skills & knowledge to design, supply materials, build, operate, maintain & monitor system, capacity & space for training and education) - Stakeholder cooperation (clarity of responsibilities, possibilities to motivate stakeholders to participate and take their responsibilities)	________
Policy & legal	- Current (national & international) policies, legislation, standard and regulations related to AD - Prospect of establishing supportive policies, legislation, standard and regulations relevant for AD	________

THANK YOU!

Appendix XI. Stakeholder workshop in Bahir Dar (25 October 2011)

AD stakeholders invited for the workshop in Bahir Dar

Stakeholder	Organization	Function	Present
Abera, Fikru (Mr.)	SNV and independent consultant	Biogas consultant	✓
Abrha, Freweyni (Mrs.)	Dream Light PLC	Manager of organic recycling centre	✓
Alemayehu, Getu (Mr.)	Bahir Dar University (BDU)	Student in sustainable energy engineering	✓
Alemnew, Getachew (Mr.)	Dream Light PLC	Manager Marketing & Sales	
Birhanu, Mengestayhu (Mr.)	Regional Bureau of Health (BoH)	Waste management & environmental pollution officer	✓
Dejene, Kassa (Mr.)	ThiGro Power	Manager, project leader	
Dr. Desta, Gizaw	Regional Agricultural Research Institute (ARARI)	Soil &water research coordinator	✓
Fenzie, Melisachew (Mr.)	Regional Environmental Protection Authority (EPA)	Head of EPA	✓
Gabbiye, Nigus (Dr.)	Bahir Dar University (BDU) Institute of Technology	Associate dean for research and postgraduate studies	✓
Getahun, Hiluf (Mr.)	ThiGro Power	Mechanical engineer	
Getahun, Zelalem (Mr.)	City Administration (CA); Sanitation, beautification and park development	Head of office	✓
Kada, Messele (Mr.)	SNV	Technical biogas advisor	✓
Metalian, Binniam (Mr.)	Regional Bureau of Urban Development (BoUD)	Officer	✓
Mohammed, Dawud (Mr.)	UNDP Local Economic Development (LED)	Programme officer	
Rodić, Ljiljana (Dr.)	Wageningen University Netherlands (WUR)	SWM expert Thesis supervisor	✓
Yitaferu, Birru (Dr.)	Regional Agricultural Research Institute (ARARI)	Director soil & water research	
Zeleke, Adafre (Mr.)	Regional Agency of Energy & Mines (AE&M)	Process owner