Feasibility assessment tool for urban anaerobic digestion in developing countries

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ABSTRACT

This paper describes a method developed to support feasibility assessments of urban anaerobic digestion (AD). The method not only uses technical assessment criteria but takes a broader sustainability perspective and integrates technical-operational, environmental, financial-economic, socio-cultural, institutional, policy and legal criteria into the assessment tool developed. Use of the tool can support decision-makers with selecting the most suitable set-up for the given context. The tool consists of a comprehensive set of questions, structured along four distinct yet interrelated dimensions of sustainability factors, which all influence the success of any urban AD project. Each dimension answers a specific question: I) WHY? What are the driving forces and motivations behind the initiation of the AD project? II) WHO? Who are the stakeholders and what are their roles, power, interests and means of intervention? III) WHAT? What are the physical components of the proposed AD chain and the respective mass and resource flows? IV) HOW? What are the key features of the enabling or disabling environment (sustainability aspects) affecting the proposed AD system? Disruptive conditions within these four dimensions are detected. Multi Criteria Decision Analysis is used to guide the process of translating the answers from six sustainability categories into scores, combining them with the relative importance (weights) attributed by the stakeholders. Risk assessment further evaluates the probability that certain aspects develop differently than originally planned and assesses the data reliability (uncertainty factors). The use of the tool is demonstrated with its application in a case study for Bahir Dar in Ethiopia.

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1. Introduction

In most cities of low- and middle-income countries municipal solid waste consists mainly of biodegradable matter (Troschinetz and Mihelcic, 2008; Wilson et al., 2012). This fraction, if not properly managed and treated, poses considerable health and environmental risks (Scheinberg et al., 2010). In addition, recovery of resources from this fraction is not yet common. Anaerobic digestion (AD) of organic waste is an effective treatment option that significantly reduces the amount of waste destined for disposal, and generates products of value, such as energy in the form of biogas and nutrient-rich digestate (Mata-Alvarez, 2003; Hartmann and Ahring, 2006; Deublein and Steinhauser, 2011). Given the fairly simple process and its suitability for warm climates it is generally considered appropriate for developing country conditions (ISAT/GTZ, 1999; Foresti, 2001; Parawira, 2009; Mshandete and Parawira, 2009).

Yet experience shows that urban AD projects in developing countries either face severe operational problems or have failed. Inappropriate technologies, lack of ownership and responsibility of operators, lack of markets for biogas and digestate, and weak business models are some of the reasons for failure. In addition, the absence of professional and academic networks, hindering legislation, lack of institutional support, and underdeveloped commercial system in the country may constitute barriers to success (Parawira, 2009; Bond and Templeton, 2011). Design and scale that do not match availability of feedstock, lack of local skills for operation, and the absence of maintenance and service support have resulted in technical failures (Bensah and Brew-Hammond, 2010). A sophisticated large-scale project in Africa stopped operation due to a lack of technical know-how, spare parts and funds to maintain the facility (Parawira, 2009). Such examples illustrate that AD projects,
although technically feasible, are bound to fail without proper understanding of the local needs, problems, capacities and priorities.

Past feasibility assessments are typically limited to an analysis of technical and financial criteria. The authors of this paper postulate that omitting the non-technical factors in feasibility assessments is one of the main reasons for the discrepancy between theoretical suitability and the observed low success rate of AD projects for organic waste treatment in developing countries. Drivers and motivations, the level of cooperation between the main stakeholders, and the institutional and legislative frameworks are considered crucial factors influencing success or failure of AD projects. An AD project is considered to be feasible if it can be sustained locally and is suitable from technical, economic, social, environmental, institutional and legislative perspectives.

This paper describes the development of a tool which

- specifies key criteria for successful AD projects, including sustainability
- allows screening and comparison of AD systems and their respective suitability in a given context
- reveals differences in stakeholders’ views, and provides a basis for discussion and negotiation
- quantifies feasibility

The tool thus assists in conducting a comprehensive, participatory feasibility assessment of AD technologies for organic waste in developing countries. It examines the technologies, their material chains, stakeholder motivation, interest and influence, and systematically examines the enabling environment in which the project will be embedded. The tool was then applied to the city of Bahir Dar in Ethiopia (Lohri, 2012).

2. Methodology

2.1. Approach and research methods

In the first research phase theoretical considerations, literature and document analysis, field visits and interviews led to the development of a draft of the feasibility assessment tool. Literature research comprised topics of anaerobic digestion (technologies and case studies), Integrated Sustainable Waste Management (ISWM) and Multi-Criteria Decision Analysis (MCDA). In the second phase of research the draft version of the tool was applied to the city of Bahir Dar, Ethiopia. Specific research methods included document analysis, observations, stakeholder analysis (Grimble and Wellard, 1997), semi-structured interviews with stakeholders and a multi-stakeholder workshop using both qualitative and quantitative techniques to solicit participants’ opinions in order to refine and adapt the tool and thereby ensure its practical usefulness.

The ISWM framework (Van de Klundert and Anschütz, 2001) was adopted to guide the semi-structured interviews and organise checklists for visits to AD projects in Ethiopia (Bahir Dar and Addis Ababa), which both helped identify relevant issues of the AD project for the assessment.

Stakeholder analysis is incorporated in the tool and was applied in Bahir Dar to determine stakeholders’ power (the extent to which their decision, influence or persuasion can achieve a relevant course of action) and interest (the extent to which the issue is a priority for them) (Grimble and Wellard, 1997). The resulting power-interest matrix helps identify relevant stakeholders for the AD project and the MCDA process.

The strong focus on (interaction among) stakeholders derives from the concept of reflexive engineering. Robbins (2007) describes it as a more integrated ethical and system-based approach to development, which values communities and the environment in which they are sited as well as the technology. In other words, while ‘traditional engineers’ search for technological solutions in a state of ‘partial ignorance’ about the physical and social environment, ‘reflexive engineers’ work with this environment in a joint effort.

2.2. Dimensions of the feasibility assessment tool

The Integrated Sustainable Waste Management (ISWM) was used as a framework of analysis. ISWM proposes a structure along three distinct dimensions: (i) stakeholders, (ii) physical system components and (iii) the enabling environment/sustainability aspects (Van de Klundert and Anschütz, 2001). Analysis of these dimensions enables a comprehensive view of the SWM system to identify options for minimizing negative impacts on public health and the environment while maximizing economic and social benefits (Zurbrügg et al., 2011).

For completeness of analysis, a dimension of development drivers was added to the ISWM framework, as proposed by Wilson (2007) and applied by Scheinberg et al. (2010). This dimension looks at mechanisms or factors that have driven development of waste management system in the past and at present. Such information is crucial to understand the prevailing concerns and determine how best to move forward in developing sustainable waste management.

Each of the four dimensions answers specific questions and together they build the structure of the feasibility assessment tool (Fig. 1).

I. WHY? (Development drivers related roughly to 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 resource recovery, reuse and recycling (valorisation of recyclables and organic materials)

II. WHO? (Stakeholders)

Identification of the main stakeholders and their roles in the SWM system.

III. WHAT? (Physical system components)

Technical components of a waste management system, starting from waste generation, and including collection, resource recovery and disposal.

Fig. 1. Scheme of feasibility assessment tool for urban AD in developing countries.
IV. HOW? (Sustainability aspects or enabling environment)

Consideration of all operational, financial, environmental, social, institutional, political and legal aspects in an SWM system.

2.3. Multi Criteria Decision Analysis

In the fourth dimension (HOW?), Multi Criteria Decision Analysis (MCDA) is used as the method to translate the obtained data in the respective categories into scores and weights to support decision making. Rather than ranking different options, as customary in MCDA, the tool assesses one option only against different sustainability criteria, making its strengths and weaknesses apparent. MCDA, a widely applied method to assist group decisions based on quantitative and/or qualitative information, simplifies a decision-making process in complex systems by selecting a restricted number of criteria and structuring them in a way that clarifies relationships, impacts and outcomes, while incorporating multiple stakeholder views (CIFOR, 1999; Lahdelma et al., 2000; Linkov et al., 2004; Buchholz et al., 2007). By highlighting both similarities and potential conflicts, MCDA enables stakeholders to better understand the values held by others (Linkov et al., 2004; Elghali et al., 2007) and fosters learning between experts and interest groups (Lahdelma et al., 2000).

3. Results – development of feasibility assessment tool

For each of the four dimensions of the feasibility assessment (Fig. 1) the tool includes a comprehensive set of questions. These can be answered by the stakeholder consultation and analysis of project documentation. Working through the tool, at key questions and issues ‘check points’ are incorporated to identify potentially disruptive patterns. ‘Supportive’ or ‘neutral’ as an answer at these ‘check points’ is pre-condition to continue with the next part of the tool. ‘Disruptive’ as an answer is equivalent to a red flag which highlights a potential project barrier. Here an intervention is required, by respective stakeholders, to address, clarify or resolve the disruptive issue.

The complete feasibility assessment tool with a user manual is available as Supplementary material to this paper and in Lohri (2012).

3.1. Dimension I: WHY?

The first dimension is an introductory part that reveals the driving forces and motivations of the main stakeholders such as project initiators, funding agencies and/or local authorities, analysing their possibly different priorities. The aim is to facilitate cooperation based on explicit and clear drivers and expectations. The set of questions is organised into four categories:

- a. Social driver (Public awareness or pressure from other stakeholders)

Was public awareness the main reason for the initiation of this AD project? Or was it rather the pressure from other stakeholders (e.g. NGOs, universities, national government, funding agencies)? If so, when, how, by whom and why was such pressure exerted? Has public awareness or pressure from stakeholder groups already triggered any ongoing activities related to organic waste AD?

- b. Environmental driver (Resource recovery for environmental sustainability)

Was recovery of resources (energy, nutrients) one of the main reasons for initiating the AD project? If so, when, how and by whom and which resource recovery activities related to AD have already been initiated, with what objective (e.g. need for locally available energy source, saving forests as source of firewood, availability of large amounts of organic waste, diversion of organic waste from disposal)?

- c. 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 were the particular financial considerations/intentions behind the AD project? Is AD of organic waste part of a broader program/set of activities to valorize resources?

- d. Other drivers

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

3.2. Dimension II: WHO?

This dimension basically consists of a stakeholder analysis, with a set of questions to help identify and characterize all stakeholders relevant to the AD project. A list of possible stakeholders helps to ensure that no relevant stakeholder is forgotten:

- Funding agency
- Governmental authorities
- Waste generators
- Design and installation specialists
- (Future) operation and maintenance staff
- End-users of AD products
- Legislator and enforcement agencies

![Fig. 2. Three main components of the AD process chain for organic waste.](image-url)
Table 1
Feasibility assessment categories, sub-categories and aspects.

| Feasibility assessment categories | Sub-categories | Aspects |
|----------------------------------|----------------|---------|
| 1 Technical-operational          | 1.1 Substrate chain | Organic waste quantity (availability) Organic waste quality Water availability & accessibility Distance to and accessibility of AD plant |
| 1.2 AD Technology                | Space availability Material availability Performance Flexibility and robustness |
| 1.3 Product chain                | Biogas quality Digestate quality |
| 2 Environmental                  | 2.1 Use of non-renewable materials | In collection and transport In construction and operation In distribution and utilization |
| 2.2 Use of chemical compounds    | In collection and transport In construction and operation In distribution and utilization |
| 2.3 Physical degradation and destruction of nature and natural processes | In collection and transport In construction and operation In distribution and utilization |
| 3 Economic-financial             | 3.1 Cost-benefit analyses | Cost of investment, operation & maintenance Revenues from biogas & digestate; savings |
| 3.2 Market situation             | Profile of targeted customer Demand and competitors |
| 3.3 Funding situation            | Sources and conditions |
| 4 Socio-cultural                 | 4.1 Willingness to change behaviour | Waste separation Biogas use Digestate use |
| 4.2 Impacts enhancing people’s capacities to meet their needs | Employment generation Fair salaries Safe working conditions Equal opportunity of inclusion Poverty reduction Distribution of burden and benefits |
| 4.3 Acceptance                   | Substrate AD technology AD product |
| 5 Institutional                  | 5.1 Stakeholder cooperation | Cooperation within AD chain Clarity of responsibilities Possibilities to motivate |
| 5.2 Institutional capacity       | Design, supply materials, build & operate Training and education Monitoring and trouble-shooting |
| 6 Policy and legal               | 6.1 AD related legislation and standards |
| Current Prospect                  | Law enforcement practices |

- Technical/research institutes and universities
- National and international NGOs
- Site residents (if any)

Each stakeholder’s driver, role and means of interventions (i.e. how is their influence practically expressed) in the AD project are assessed. Of particular interest is to establish the level of power (control) that a stakeholder may have over the proposed AD chain, and the stakeholder’s interest towards the AD project, which can be supportive, neutral or disruptive. The resulting interest-power matrix provides the first ‘check point’ in the tool. Where stakeholders with medium or high power show a disruptive interest in the AD project, a red flag must be raised so that the issue is addressed, clarified or resolved in collaboration with the respective stakeholders.

3.3. Dimension III: WHAT?

This dimension reveals information about the physical components and flows in the proposed AD project. A supply chain perspective is taken to allow a structured analysis of the AD system, which systematically assesses main components relevant for a smooth operation of the entire process. Supply chain is understood as “a set of three or more entities (organizations or individuals) involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer” (Mentzer et al., 2001). Effective supply chain coordination implies supply chain actors working together in a coordinated way towards a unified system (Arshinder and Deshmukh, 2008; as cited by Gold, 2011). The process chain of AD comprises three main components as shown in Fig. 2.

A set of questions are linked to the three chain components, to determine the level of detail considered in the AD project proposal.

- Substrate chain: sources, quantities and qualities of substrate, seasonal variations of waste generation, proposed collection and transport of the waste to the AD site.
- AD technology: the proposed AD technology, location and space requirements, range of substrate quantity and quality for sound operation of the AD system, water and energy requirements, expected gas yield, expected quality of biogas and digestate, post-treatment steps for biogas and digestate, control devices.
- Product chain: proposed way of biogas distribution, distance between AD site and users of biogas and digestate.

The answers are used to draw a flow diagram of the AD chain. If the proposed AD project is an element of a set of technologies, these need to be included to the extent to which they affect the AD project with regard to the four dimensions of the tool.

3.4. Dimension IV: HOW?

The questions are grouped into six main categories, according to the sustainability aspects of ISWM (pillars in Fig. 1). The importance of sustainability considerations for human development is well established in literature (e.g. Norton, 2005). In this research the
Examples of uncertainties in technical-operational feasibility assessment category. Uncertainties related to the correctness and reliability of data, assumptions, estimations and information used for the feasibility assessment are taken into account through an additional list of questions grouped by six feasibility categories in the HOW-dimension. Uncertainty is quantified in such a way that the weighted scores can be reduced by half if the uncertainty is considered to be very high. A few examples of uncertainty factors for the technical-operational feasibility category are presented in Table 3.

3.5. Consideration of uncertainty

The tool is designed to be used by an ‘expert’, i.e. a person with certain in-depth knowledge on AD. This person leads the assessment, while working together with the local stakeholders, according to the principles of reflexive engineering.

Step 1 The ‘expert’ answers the questions pertaining to the first three dimensions of the tool (WHY?, WHO?, WHAT?) by gathering information from stakeholders. These first three dimensions ask for descriptive answers to outline the context and set-up of the proposed AD project.

Step 2 Again with information from local stakeholders, the user answers the questions of the dimension (HOW?), selecting one of the pre-set answers. These are translated into scores which feed into the feasibility matrix based on the six sustainability categories.

Step 3 Again in consultation with the stakeholders, the expert rates the uncertainty of each given answer as high or low; these

Table 2
Examples of feasibility assessment matrix.

| Technical-operational feasibility category | Not feasible (−10) | Neutral (0) | Very feasible (+10) |
|------------------------------------------|-------------------|-------------|---------------------|
| 1.1 Substrate chain                       | Lacking more than 20% required for sound operation | Between 20% less & 20% more for sound operation | Exceeding required amount by more than 20% |
| 1.1 Substrate chain                       | Poor              | OK for moment, needs to be improved | Good |
| 1.2 AD technology                         | Internationally available | Nationally available | Locally available (<30 km) |
| 1.3 Product chain                         | Not suitable      | Moderately suitable | Very suitable |
| 1.3 Product chain                         | Deviation from literature: more than 20% lower | Deviation from literature: within 20% either side | Deviation from literature: more than 20% higher |
| 1.4 Clear maintenance strategy           | Not included      | Partly included     | All included |
| 1.5 Digestion quality compared to the required quality (texture, pH, NPK-, pathogen-, heavy metal content) for digestate use | >=500 m | 100–500 m | <100 m |

Table 3
Examples of uncertainties in technical-operational feasibility assessment category.

| Technical-operational uncertainties                                      | Uncertainty factor |
|--------------------------------------------------------------------------|--------------------|
| Risk that required quantity and quality of substrate will not be delivered (due to whatever reasons) | x                  |
| Risk that required material for construction, operation & maintenance will not be delivered | x                  |
| Risk that maintenance will not be done                                    | x                  |
| Risk that chosen location of the AD system will not be suitable in the future (e.g. cut-off roads) | x                  |
| Risk that assessment of technical-operational feasibility is not reliable (lack of data, wrong calculation, inadequate estimations) | x                  |
| Average factor to multiply weighted score                                 | *0.8               |
are then combined into an average uncertainty factor per category.

Step 4 The expert facilitates a stakeholder interaction to jointly assign importance weights between one (1) and ten (10) to each of the six main feasibility categories, whereby weight of one implies that the category is not really important for success to AD project and the weight of ten implies the category to be essential for success of the AD project. Weighting can be done with each stakeholder individually or in a workshop, whereby the latter is deemed more appropriate as it allows clarifications and fosters discussions about the proposed project, and the tool itself. The stronger the acceptance for the tool, the higher the chance will be that the results of the feasibility assessment will be taken seriously and owned by stakeholders.

Step 5 The results of the feasibility assessment are visualized in two Excel graphs:
- Overall feasibility of AD project: combines the results of all stakeholders and illustrates the most important strengths and weaknesses of the proposed project. Scores and weight are multiplied and visualized by a bar chart for each main feasibility category. In addition, the uncertainty range is depicted by a grey zone.
- Stakeholders’ individual assessment results illustrate the importance weights that each stakeholder allocates to the six sustainability categories.

Step 6 The results are presented to and discussed with stakeholders, whereby the discussion focuses on possible measures to enhance sustainability of the AD project.

The tool can be adapted for each context to suit the specific local circumstances. For example, the acceptable distance between source of waste generation and the treatment site might vary depending on the scale of the proposed project.

4. Results – application of feasibility assessment tool in Bahir Dar

4.1. Development drivers (WHY?)

Since 2008, the SWM system in Bahir Dar, a city of 220 000 inhabitants in the northwest of Ethiopia, is set up as a collaboration between the municipality and the private company Dream Light (DL). This public-private partnership has improved waste collection coverage from 51% in 2005 to 71% in 2010 (UNEP, 2010). Waste is still predominantly disposed of in an open dumpsite. In 2008, Dream Light initiated a project of integrated organic waste recycling, which includes composting, anaerobic digestion and charcoal-briquetting. Financial reasons are the main driving force for DL, i.e. to generate revenues by valorising part of the collected waste. The main interest of the municipality is to have a clean city for tourists and citizens of Bahir Dar. Although the municipal authorities appreciate Dream Light’s waste collection efforts and hope for the success of the integrated organic waste recycling centre, they are not actively involved in the project. UNDP provides funding as loan to Dream Light, administered through the municipality. The main motivation and focus of UNDP is foster successful private-public partnerships which lead to good, fast and effective development.

4.2. Stakeholders (WHO?)

The interest-power matrix is shown in Fig. 3 based on information provided by different stakeholders.

The tool can be adapted for each context to suit the specific local circumstances. For example, the acceptable distance between source of waste generation and the treatment site might vary depending on the scale of the proposed project.
Bakeries are rated as stakeholders with a disruptive interest (but with very limited power) because the generated biogas will be used to bake bread, which is a competition to the bakeries.

4.3. Physical components (WHAT?)

Fig. 4 shows how the planning and implementing company (ThiGrow Power), engaged by Dream Light designed the system. It reports 650—700 kg/day of required substrate quantities for the AD system (62 m³), 950 kg/day for the briquetting factory and 450 kg/day for the composting pit (150 m³). The types of organic waste for each technology are not specified, but an average total solid content of organic waste of 25% and volatile solid content of 90% are assumed.

The recycling centre is located about 3 km in the south of the Bahir Dar city centre, 1 km away from the open dumpsite ‘Gordma’. All waste designated for the recycling centres is collected by Dream Light from one source only: the main vegetable market of Bahir Dar. Some sorting takes place at the centre to remove inorganics. The proposed AD technology is an underground fixed-dome system, SINIDU-model with a gas storage volume of 13 m³ and an active volume of 49 m³. According to ThiGrow Power, the expected gas yield is 12 m³ biogas/day, of which 8 m³ (68%) is CH₄, 3.6 m³ (30%) CO₂ and the remaining 2% trace gases. The biogas is desulphurized by a H₂S-filter consisting of a container filled with iron chips and then used in a gas fuelled bread oven to produce 500 breads per day. The biogas energy content will be 72 kWh per day (12 m³ = 6 kWh/m³)

The liquid digestate is directed into the compost pits where it is mixed with fresh organics, thereby speeding up the composting process. Dream Light purchased 100 ha of agricultural land approximately 400 km from Bahir Dar in direction of Gonder. The aim is to use the produced compost for cultivation of cotton and sesame seeds.

4.4. Sustainability aspects (HOW?)

To help answer the questions of the feasibility matrix Dream Light, ThiGrow Power, SNV and the City Administration of Bahir Dar were consulted. The answers were translated into scores as presented in Table 4. Questions answered with ‘not feasible’ are mentioned and explained in more detail. The explanation of each score can be found in Lohri (2012).

Two examples of issues assessed as ‘not-feasible’ are described in more detail below:

(1) Low biogas assumptions: In the project proposal the expected biogas yield is estimated at 12 m³/day (51 L CH₄/kg VS), based on a daily input of 700 kg (wet weight) of substrate (equals 157.5 kg VS/day, assuming 25% TS and 90% VS). This yield is low compared to figures in literature, e.g. 200–530 L CH₄/kg VS (Khalid et al., 2011).

(2) Institutional capacity lacking: There is an apparent lack of institutional capacity (knowledge and experience) of the main stakeholder to design, build and operate such a large AD system. This also reflects in the inaccurate assumption of expected biogas yield described above. In addition, the capacity to train staff to do trouble-shooting and to conduct process monitoring is very weak.

Table 4

| Feasibility categories | Score | Issues in questions answered with ‘not feasible’ |
|------------------------|-------|--------------------------------------------------|
| 1 Technological-operational (average) | 3.5 | |
| Substrate chain | 2.5 | Measurement of daily input quantity inadequate |
| AD technology | 0.6 | Transfer stations lacking; geotechnical conditions unfavourable, maintenance strategy missing |
| Product chain | 7.5 | Long distance from AD site to digestate use, low biogas yield assumptions (1) |
| 2 Environmental (average) | 3.3 | |
| Non-renewable substances | 0.0 | |
| Chemicals compounds | 0.0 | |
| Degradation of nature | 10 | |
| 3 Financial-economic (average) | 5.0 | |
| 4 Socio-cultural (average) | 3.3 | |
| Acceptance | 0.0 | |
| Willingness to change behaviour | – | |
| Increase people’s capacities | 6.7 | |
| 5 Institutional (average) | 0.8 | |
| Institutional capacity | –5.0 | Institutional capacity to design, supply materials, build, operate, provide trainings & education, carry out process monitoring and trouble-shooting (2) |
| Stakeholder cooperation | 6.7 | |
| 6 Policy & legal (average) | 2.0 | |
| AD policies | 2.0 | |
Fig. 5 presents the overall feasibility of the AD project proposed in Bahir Dar. The bars combine scores from the feasibility assessment matrix and average weights given by the stakeholders. None of the six main categories shows negative scores. Financial-economic feasibility was based on data supplied by DL and was assessed to be good (albeit with a considerable level of uncertainty with regard to data reliability) as well as technical-operational, environmental and socio-cultural feasibility. In contrast, institutional feasibility was assessed to be low, due to low scores in ‘institutional capacity’. Feasibility in the policy and legal category is low and shows a considerable range of uncertainty indicating that although current policies are not disruptive to AD, it is difficult to predict if future policies, rules and regulation might disadvantage AD projects.

Feasibility scores and weights assigned by Dream Light are shown in Fig. 6(a). The technical-operational category is considered most relevant for the success of the AD project, followed by the institutional category. Given its low score, special emphasis must be put on improving institutional capacity to ensure that this will not endanger success of the project.

In comparison, Fig. 6(b) shows the view of the municipality that considers social criteria to be most important for the success in AD project. Given the close dependency between Dream Light and municipality, it is crucial for Dream Light to understand and discuss why the municipality highlights the socio-cultural feasibility category. 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 putting together a successful AD puzzle.

Figures 5 and 6 illustrate the scores and weights assigned by different stakeholders, with the uncertainty range indicated by the bars. The scores range from -100 to 100, with higher values indicating greater feasibility.

Scores and weights by other stakeholders (funding agency UNDP, biogas advisor of SNV), show a good overall feasibility, with attention required for the issue of institutional capacity building.

5. Discussion

5.1. Feasibility assessment tool

A comprehensive, participatory tool that specifies key criteria for successful AD projects, including sustainability was developed and applied. In general, the tool achieves its objective by supporting decision makers in assessing the feasibility of a proposed AD project. Like other decision-making tools based on elicitation of (expert) opinions (Long and Schweitzer, 1982; Cooke, 1991; Otway and von Winterfeldt, 1992; Van Steen, 1992), a certain degree of subjectivity remains as intrinsic characteristic of the tool, particularly in the HOW-dimension of the feasibility matrix. However, if the assessment is done in a transparent way, as proposed here, each answer (score, weight and uncertainty factor) can be discussed among stakeholders to find a best possible consensus.

In their feedback, stakeholders — participants of a workshop in Bahir Dar — expressed their preference for an open and transparent process of attributing weights, arguing that it helps prevent misunderstandings, enables fruitful discussions and facilitates sharing and mutual learning in an open atmosphere as compared to an anonymous process.

In addition to the advantages in its current form, the feasibility assessment (ex-ante) tool can, with a few modifications, be transformed into a project evaluation (ex-post) tool to highlight strengths and weaknesses of an existing project and its operation, or analyse and determine causes of failure of projects that failed in the past. The tool can also be modified to assess feasibility of other waste recycling and resource recovery projects, as confirmed by reactions from practice (Visvanathan, 2012).

5.2. Application of feasibility tool on AD project in Bahir Dar

The application of the feasibility assessment tool in Bahir Dar revealed several factors that potentially can lead to success of the AD project under consideration. Firstly, Dream Light, the company that initiated the project and owns the facilities, has responsibility and control over the entire supply chain. Thus, the company can rapidly influence all activities along the AD chain to ensure project operations and thus viability. Secondly, a diversified portfolio of waste recycling products (compost, biogas, charcoal-briquettes) targets different market segments and thus distributes risk. At present, high demand is expected for all waste-derived products:
The feasibility assessment tool was applied on a single project in Ethiopia. Further validation of the tool in other AD projects and countries is needed. Feedback from users is therefore welcome to further improve the tool. The complete feasibility assessment tool with a user manual is available as supplementary material to this paper and in Lohri (2012).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2013.04.028.

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