Performance assessment for small-scale biogas plants in Sub-Saharan Africa

by

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Preface

This thesis has been developed as part of the fulfilments for the Master of Science program in Sustainable Energy Technology, organised at the Faculty of Electrical Engineering, Mathematics and Computer Science at Delft University of Technology.

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Marco Cioli October 31st, 2019

Summary

The African energy sector is developing vigorously but yet the Sub-Saharan African region presents critical challenges in terms of global energy systems, such as extreme poverty and inequality, poor infrastructure and relatively low education level.

In recent years, a special focus is given on renewable energy solutions. Biogas technology is playing an important role, especially for rural communities, due to its economic feasibility and capacity to produce clean energy from animal manure or waste. In addition, the slurry produced as a by-product can be recycled as a high-quality fertiliser due to its high nitrogen content. However, the adoption of this technology has never scattered, despite the diffusion of many programmes, such as "Biogas for Better Life - An African Initiative" or "Africa Biogas Partnership Programme" (ABPP), in the whole SSA region. Naturally, since the appearance of the first biogas system, the number of installation has increased considerably, but still, several limitations need to be improved in terms of performance and acceptability of the technology.

Biogas production issues are generally connected with poor maintenance of the plant, characterised by the unavailability of a daily and regular feeding activity, inadequate cleaning and stirring system, and inefficient use of biogas. In addition, the overlooking of socio-cultural values can contribute to the expansion of performance issues since it affects directly the work approach and behaviour of biogas owners.

For these reasons, the ambition for this research was to establish a qualitative study project that investigates firstly the technical and socio-cultural aspects that influence the small-scale biogas plants performance in the Sub-Saharan African context. Moreover, it analysed the causes of possible failures of these type of system in light of the current socio-cultural context. The goal is to provide a list of recommendations, which take into account the most frequent issues occurred in biogas plants, in order to tackle these challenges and achieve an efficient biogas production. It will, therefore, answer the following research question:

What are the causes of the poor performance of a small-scale biodigester in Sub-Saharan Africa and how can this performance be improved?

A clear distinction between two types of indicators has been proposed, where the first group reflects the assessment criteria to analyse the technical and operational characteristics of the biogas plant. The second group is characterised by cultural institutional parameters that describe already established socio-cultural values, called "dimensions", about the internal management and the business environment that influence the running and maintenance of the biogas system.

During the literature research, 4 cases were established where a complete description of the performance and maintenance of small-scale biogas plants, located in a specific geographical and socio-cultural context, was supported by interviews of the biogas owners and some biogas providers. In addition, during the field research over a period of three months

in South Africa, a case study was developed by interviewing several expert stakeholders of biogas technology and by visiting five small-scale biodigesters in the area. The scope of the research includes small-scale biogas plants that were having issues in their biogas production in the Sub-Saharan African area. Case studies were consequently analysed through the tool composed by the research framework (two tables) developed in the literature research. At the end of the analysis, ten most occurred issues in the case studies were founded and evaluated in order to directly link the indicators previously mentioned with the factors that influenced the issues analysed. The findings were consequently adopted to confirm and adjust the tables.

The first findings include the technical and operational issues that mostly affect small-scale biogas plants in the SSA context. In a technical point of view, gas leakage is the most common issue occurred, and the plant design is a crucial aspect that influences the future performance of the biogas system. The materials used for the construction are fundamental in order to avoid cracks or deterioration of the system. Cleaning the gas produced from water vapour and hydrogen sulphide is another important aspect that could avoid more than 60% of the gas leakage in the system.
The main operational issues that negatively affect the biogas performance are the blockage of the inlet pipes, insufficient feeding activity, and the corrosion of biogas appliances. The first challenge can easily be resolved with a proper filtering and stirring system, that could remove unwanted materials from the feedstock and ease the inflow of the latter inside the digester. Proper maintenance is fundamental to enable the biogas plant to perform optimally every day. In this way, the users would be able to notice even small problems that can be resolved in a few hours. All these activities require constant monitoring to control constantly the biogas performance and to observe if any problem occurs during the day. The amount of feedstock and water added in the plant is the most important information that necessitates a daily control but also other important parameters such as temperature, gas production, pH value, and agitation system.

In terms of socio-cultural factors, through the case descriptions, it was possible to notice a common hierarchical attitude towards their workers among the biogas owners interviewed. This aspect was supported by a lack of communication between workers and owners hindering the interest of the first to share opinions and to take initiatives. In addition, it was evident the necessity of adequate time management and planning method because several operational issues were indirectly influenced by this factor. For these reasons the teamwork, a mixture of hierarchical management style with a more egalitarian communication and cooperation with the workers is recommended.

The business environment plays a crucial role in the performance of biogas plants. The general context is characterised by the presence of vertical networks where limited cooperation among members of different groups dominates, and biogas owners need to invest time and money to build trust and cooperation with future partners, such as biogas providers or other suppliers. As a result, the lack of technical support after the installation of the system from the biogas providers to biogas users hinder adequate maintenance since the owners usually don't have sufficient technical knowledge to evaluate any problems. A second result is the diffusion of a profound lack of trust that broadens the distance between users and providers. Lastly, the support of the government for the diffusion of the biogas technology, in terms of knowledge spreading and financial operations, is still weak.

All these aspects are supported by limited practical knowledge on biogas technology and a not professional attitude of the owners, that struggled to control the productiveness of their plants and their workers.

Following the findings among the case studies analysed in Sub-Saharan Africa, several recommendations are proposed for effective biogas productiveness in the SSA context. These include:

- Cooperation between biogas providers and users: a proper follow-up service strategy should be developed where demonstration, training sessions and a regular check-up should be provided by biogas companies.
- Suitable installation of the biogas plant: a particular attention should be given to the design of the plant, characterised by the size, the construction materials, the cleaning and the stirring system.
- Optimisation of water quantity: biogas providers should consider during the installation the amount of time and energy required to supply the water demanded to the biogas plants.
- Appropriate maintenance of the plant: a proper daily, weekly and annually maintenance of the biogas plants is fundamental to keep the system in optimal conditions.
- Sufficient monitoring system: activity monitoring and data record can improve the performance of the biogas plants and the workers.
- Improve capacity: training sessions and national programmes should be promoted in order to spread not only the biogas knowledge but also the proper education for running a biogas business taking into consideration also the internal management and the business environment.
- Teamwork: biogas owners should develop a combination of a hierarchical management style with a improved communication and cooperation with the workers.
- Development of National Programmes on biogas technology: The governments should focus on the promotion of the biogas technology, especially in rural areas, to improve the living standard of their citizen.

Contents

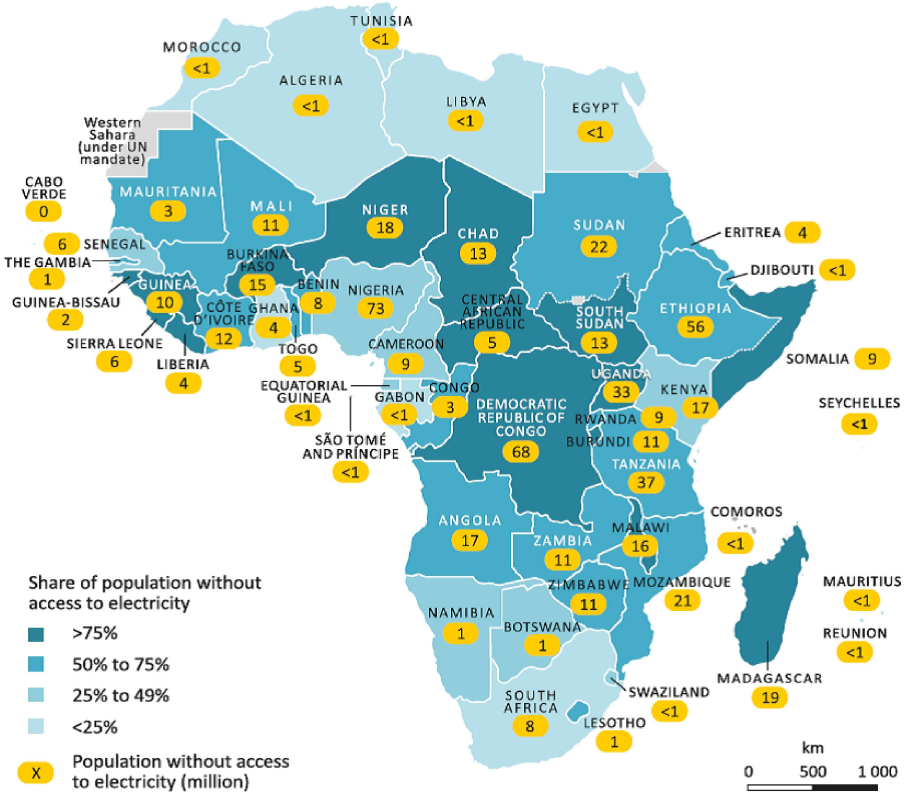
List of Symbols & Abbreviations

SSA	Sub-Saharan Africa
AD	Anaerobic Digestion
NGO	Non-Governmental Organisation
NDC	Nationally Determined Contribution
GDP	Gross Domestic Product
IEA	International Energy Agency
O&M	Operation and Maintenance
ABPP	Africa Biogas Partnership Programme
NPO	Non-Profit Organisation
TS	Total Solid
TOS	Total Organic Solid
VFA	Volatile Fatty Acids
COD	Chemical Oxygen Demand
C:N	Carbon - Nitrogen
OLR	Organic Loading Rate
CSTR	Continuous Stirred tank Reactor
HRT	Hydraulic Retention Time
SMEs	Small-Medium Enterprises
TKN	Total Kjeldahl Nitrogen
SRT	Solid Retention Time
GRP	Glass-fibre Reinforced Plastic
SNV	Stichting Nederlandse Vrijwilligers - Netherlands Development Organisation
BTWAL	Biogas Technology West Africa Limited
HDPE	High-Density Polyethene
ARTI-TZ	Appropriate Rural Technology Institute Tanzania
CAMARTEC	Centre for Agricultural Mechanization and Rural Technology
SNNPRS	Southern Nations, Nationalities and Peoples Regional States
KARI	Kenya Agricultural Research Institute
PBD	Prefabricated Digester
OCD	Onsite-Constructed Digester
CEO	Chief Executive Officer
CTO	Chief Technology Officer
IPPs	Independent Power Producers
PEETS	Process Energy Environment Technology Station
ICT	Information and Communications Technology

1

Introduction

Africa's energy sector is vital to its future development and yet remains one of the most poorly understood regions within the global energy system, especially for the countries below the African Sahara, also known as Sub-Saharan Africa (SSA), where critical challenges are still presented such as high levels of poverty and inequality, shortage of infrastructure and relatively low levels of productivity and skills.



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Figure 1.1: African population without electricity access by country, 2016 (Adapted from [93])

Sub-Saharan Africa represents a region culturally and economically diverse with a unique potential to develop rapidly. Six countries (Burkina Faso, Côte d'Ivoire, Ethiopia, Rwanda, Senegal and Tanzania) were expected to grow at more than 6% in 2017, but lower growth prospects for the rest of Sub-Saharan Africa brings the region average down to 2.6% [93]. The last decade has been characterised by a strong economic growth due to financial aid, mature governmental policy and actions from Non-Governmental Organisations (NGOs) [28]. A new mindset and a different determination to build their own development path have become established among African people as a result of a more mature policy framework. Among the 53 African countries that submitted Nationally Determined Contributions (NDCs) at COP21, 34 mention energy access as a key enabler for development [93]. There are also dozens of energy investment initiatives, including the New Deal on Energy for Africa, which aims to achieve universal access by 2025 by mobilising up to \$50 billion of additional funding [38] [114].
However, extreme poverty and inequality are still the main issues in this region, with around 400 million people living in severe underdevelopment conditions [133] and over 600 million without access to electricity (nearly half of total African population), especially in rural area where the lack of access to energy is believed to be the most crucial challenge [15]. Figure 1.1 shows the discrepancy of the access rate for African countries in 2016. Globally, populations without access to any sustainable form of energy represent the poor, and access to energy is considered one of the major factor that leads to improve living conditions [66].

The need for alternative renewable energy sources from locally available resources cannot be overlooked. Recently, the interest in biogas as an appropriate and economically feasible energy source has increased in SSA for its capacity to be located anywhere a waste feedstock is available. This renewable solution has proved very useful for local communities located in rural areas, where waste is not lacking as well as the need for cheaper energy and cleaner cooking fuel. Biogas plants are biological systems involving various interacting microorganisms that anaerobically degrade organic matter. The main product is biogas, a methane-rich gas (CH_4) that can be used as a renewable fuel for vehicles or to generate heat or electricity for local use or distribution into the grid. Aside from the ability to contribute to the energy supply and the environmental benefits, biogas offers some other distinct advantages compared to other renewable energy sources. Firstly, the performance of a biogas digester is not dependent on any external conditions as long as the installation is maintained properly and correctly supplied with feedstock – unlike for example solar cells or wind turbines [46]. Second, the waste that is produced by the biogas digester can, in turn, be used as a high-quality organic fertiliser due to its high nitrogen content. Additionally, biogas digesters can easily be installed in rural areas as long as there is sufficient feedstock available and can thereby help to alleviate poverty in these areas by providing additional sources of income [49].

The production of biogas involves four consecutive biological processes: hydrolysis, acidogenesis, acetogenesis and methanogenesis. If one of these processes is negatively affected in any way there is an immediate influence on the other processes and the biogas plant can become unstable [31]. Technical issues are often connected with poor management of the plant, described as unavailability of feedstock or water, inadequate maintenance of digester, lack of planning, insufficient foresight, inefficient use of biogas, lack of communication and lack of professionalism. Also, socio-cultural values affect directly the work approach and behaviour of biogas owners, and the overlook of these dimensions can contribute to the bad performance of a biodigester [105]. These dimensions take into account two different systems of institutions and values that structure the behaviour of many entrepreneurs that are explored in this research. It should be stated that many process imbalances or failures can be avoided by a good operation practice led by efficient internal management of the workload and an appropriate business environment that enables the good performance of the biogas plant.

Working with planning, targets and records, as well as technologies, requires education and training. However, most of the employees in the agricultural sector only attended the mandatory primary level of education, while secondary education is usually only reachable for wealthy families [119]. However, even when there is an appropriate education level, a transition to a modern system of values is also necessary for entrepreneurs to improve the performance of their biogas technology.

Society and technology are unequivocally intertwined and thus the social context should be considered when analysing the development of new technology. The introduction, the diffusion and the use of new or improved technologies into new social and economic settings are the results of activities of actors who are influenced by specific institutional characteristics, such as government policies, market structure, user preferences, cultural values and social norms ([19],[81]).

This thesis aims to investigate the cultural and institutional influences on Sub-Saharan African people that enable or hinder the biogas plant project success. Moreover, it examines the causes of possible malfunctions of biodigesters related to the internal management and the biogas production process. The goal is to develop an integrated system model, which takes into account all the factors around a bad performance of a biogas plant, in order to overcome the issues and achieve an efficient and successful scenario of future projects.

Focusing on this chapter, the first paragraph provides the general context of Sub-Saharan Africa. In the second paragraph, some practical values will be provided that cause some of the impedance for biogas projects in SSA. Next, the theoretical significance will be discussed that this thesis will address. This will be followed by the research objective and scope and the research questions. Lastly, the thesis outline will be discussed.

1.1. Background of Sub-Saharan Africa

Sub-Saharan Africa represents the African region south of the Sahara Desert. It is composed by 48 countries and 4 sub regions: Central Africa, East Africa, West Africa, and Southern Africa [10]. The population counts 1.05 billion citizens and thus is around 86% of total African population [26]. Moreover, SSA is occupied by the world's poorest countries with 47% of the population living with less than $1.25 a day [21], although this trend seems to maintain a moderately steady decline during recent years.

Analysing economic data, it is possible to notice that SSA continues to show marked economic growth overall with a nominal gross domestic product (GDP) per capita of $1,553.767 in 2017 and a projected expansion of 3.3% in 2018 [37]. Region development is supported by strong investments in infrastructure and is sustained by a substantial production in mining, primary and service sectors, with a constant domestic demand [36]. However, irregular growth characterises the economy since some countries still experiencing a large government debt and a financial system poorly developed [21].

Lack of energy sources makes hard to meet the energy demand for the majority of SSA countries that have to rely on fuel imports [94], moreover the high cost of average electricity price with poor supply and distribution infrastructure induced around 620 million people in the region without electricity access [96]. The most affected by electricity limitations are rural households, which are characterised by a low electricity access rate - around 11% - and depend on several biomass resources, such as cow dung, fuel wood, charcoal and crop residues as traditional fuels [91].

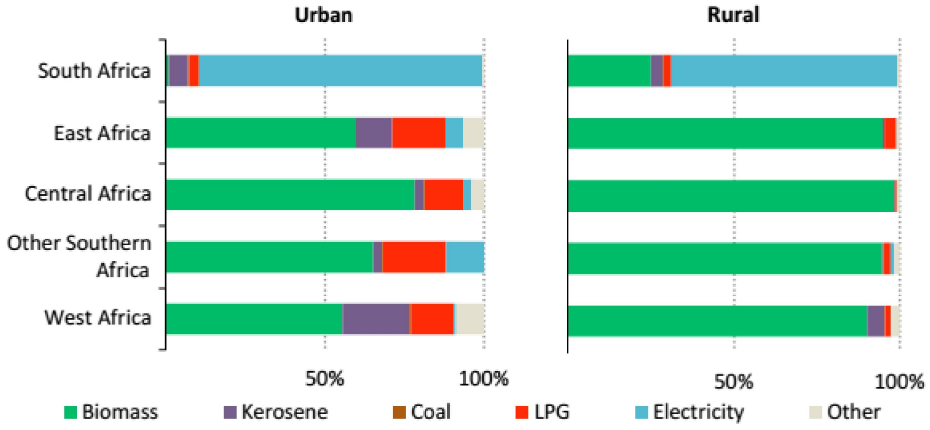


Figure 1.2: Types of fuel used for cooking by African regions, 2015 (Adapted from [93])

In addition, the use of traditional open fire stoves with not sustainable fuels represents a big issue for SSA population as the International Energy Agency (IEA) has estimated 75% of the population - around 730 million people - without clean cooking systems [89].

Different negative impacts are provoked by the collection and use of non-renewable fuels such as health hazard - like pneumonia, acute infections of the lower respiratory tract and chronic obstructive pulmonary diseases - caused by indoor pollution, environmental deterioration induced by either deforestation or soil erosion or possible flooding, and also social-economic barriers [99].

At household scale, especially in rural areas, the adoption of biogas technology leads to improve drastically the people's livelihood since it represents a cost-effective and sustainable energy source, that reduces or excludes the fossil fuel or firewood demand for cooking, makes the sanitation acceptable and boosts soil fertility and agriculture production with the utilisation of organic fertiliser. In addition, using this technology it is demonstrated that relevant annual financial savings can be achieved. Typically, a family that leaves in the rural area and uses a biodigester can save between $204 and 342 per year [128]. Biogas has the advantage, compared with the other renewable energy sources, of being available wherever is ready to use a sufficient organic feedstock. According to Wamwea [128], among 176 biogas owners in Kenya that respond to a survey, the 62% is fully satisfied with their biogas systems, and the most important reason for their satisfaction was the economic savings (around 47%).

In Africa, several international organisations and foreign agencies have stimulated the diffusion of biogas technology through their publications, visits and projects. Nowadays, some biogas plants have been installed depending on a different type of feedstock such as municipal waste, industrial waste, animal dung and human excreta. Although small-scale biodigesters are mostly used by schools, health clinics and mission hospitals, rural farmers, and built by local constructing companies, most of the plants operate for just a few months after the installation due to poor and inadequate management [76]. According to Castro [20], whenever a biodigester failure was occurring the reason was due to a lack of interest, lack of trying from either the owner or his personnel. Most of the time the workers were not awarded for their efforts to operate properly the biodigester and they lost their motivation. Moreover, many biogas digesters that were constructed decades ago as pilot projects are no longer operational and this influences negatively the social acceptance and mindset for this technology [77].

1.2. Practical significance

The need for alternative decentralised renewable energy resources is becoming increasingly crucial and urgent observing Africa's energy situation. Recently, the interest in biogas as an appropriate and feasible energy source has increased in Sub-Saharan Africa due to its capacity to be located everywhere. However, in the region the adoption of small-scale biodigesters has been limited by several factors which may be either technical (low production rates, overfeeding, gas leakage, poor management of digester) or social-economical (high investment cost, lack of skilled human resources, poor promotion of the technology, lack of dynamic attitude). Everson and Smith [35] argue that once the biodigester is installed and after months of operation, most of the small-scale biogas plants encounter breakdown or malfunctions of the technology. Some of the constraints that are hampering small-scale biogas plants to operate efficiently will be discussed below. The correct management of the biodigester is therefore crucial for its optimal running and the realisation of financial benefits. Biogas production is composed of four consecutive biological processes: hydrolysis, acidogenesis, acetogenesis and methanogenesis. In case of malfunction of one of these steps, the other processes are immediately negatively affected and the biogas plant becomes unstable. In addition, Thairu [126] discussed that lack of an adequate O&M strategy can be influenced by poor management of biogas plant, which is described as inadequate planning, lack of foresight, inefficient time allocation and stifled communication. The objective of this thesis research is to provide an evaluation assessment that could analyse the performance of a small-scale biogas plant, in order to provide recommendation for the optimal running of the plant and for the success of future biogas projects.

1.3. Theoretical significance

After some practical awareness in the current SSA biogas technology environment, this section aims at the theoretical relevance presented in this research thesis.

This research aims to contribute to the academic body of knowledge by considering the impact of both technical and social-cultural factors around the performance of small-scale biogas plants in SSA. Four main areas characterise a biogas plant in all its aspects and they will be described. First, the technology part will be analysed considering the biogas production process, the biodigester technology and the technical parameters that affect the performance of the whole process. Second, the operational management of the digester will be considered, which takes into consideration the operational issues that can hinder the good performance of the digester. Third, the internal management style will be addressed in terms of behaviour and strategic approach of local biodigester owners in the SSA context. The last area will be the business environment around a small-scale plant, that should promote the entrepreneurial activity in the biogas sector, creating the perfect conditions to maintain a constant production yield of the project.

Many of the studies found in the literature about biogas performance in Sub-Saharan Africa are focused just on the technical and operational perspective [104] [77] [42]. It is not common to find scientific reports or academic papers that analyse both the technical and the socio-cultural aspects of a biogas plant in a developing country context. According to Rupf et al., the success of a biogas project in SSA is not only the result of proper maintenance of the technology but also of a suitable socio-cultural environment that enhances the good operating of the biogas plants [105]. In addition, Mwirigi et al. in their research affirmed that the key issue for the biogas technology in SSA is to investigate on the socio-cultural and economic factor that limited the dissemination of this technology, despite the viability, sustainability, and effectiveness of the technology is demonstrated [78]. The mere supervision over technical and operational parameters is not sufficient for a lasting good performance of a small-scale biogas plant. To be successful and constant, an analysis of the socio-cultural values that influence the running of the plant is necessary. This thesis aims to evaluate both technical and socio-cultural aspects that can affect the performance of a small-scale biogas plant.

1.4. Research objective and scope

The objective of this research is threefold. Primarily, it aims to analyse the general context of biogas and to determine the technical, operational, social and cultural conditions that affect the performance of a biodigester. Second, it will explore the manifestations of the four main aspects in the SSA biogas context, by developing a set of parameters per each area that can be used to analyse the management of a small-scale biogas plant and its environment around it, as well as identifying necessary changes to enhance the biodigester performance. an evaluation assessment will be developed and it will be used to analyse the case studies but also it will be validated through the evaluation of the issues that permits to find interconnection between the several parameters of the model. Lastly, several recommendations will be described in order to find the appropriate transition solutions occurring in the four main areas, that aim to achieve the ideal scenario and improve the performance of the biodigester. In order to achieve these objectives, a preliminary multiple case study approach is used, which involves deep literature research on small-scale biogas plants installed in the SSA region, case developments and multiple cross-case analyses.

The scope of the research will be limited to small-scale biogas plants in Sub-Saharan Africa in order to confine the application of biogas to household, small community, school, or domestic farm. The dimension of the digester will range between $4m^3$ and $50m^3$, with an application of biogas for cooking, heating and generating electricity. The reason is that more than 90% of the total biodigesters in SSA are small/medium-scale ($< 100m^3$), and a little amount of them are fully operational [76]. The biogas consumption of an average

household (with 5 members) is calculated around 16-37 m^3 per week for cooking, and 8-22 m^3 per week for lighting, resulting with an average biodigester of 7-17 m^3. For a typical small-scale biogas plant of a rural community, the average volume ranges between 16 and 50 m^3 [25]. In Ethiopia, about 40% of the current biodigesters installed are not operating [110], while in Ghana 28 out of 50 (around 55%) small-scale biodigesters analysed are totally broken-down or at least presents some issues [9]. When we talk about partially or total not operating biogas plants, it means that less than half of the total potential biogas production is actually produced.
This research is composed for the fulfilment of the Energy & Society track of the Master of Science program Sustainable Energy Technology at the faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) of the Delft University of Technology. Hence, the objective and scopes of this thesis meet the criteria conferred by the program.

1.5. Research questions

In order to implement an integrated system that could induce the social, economic and technical development of biogas technology for small size application, the following research question has been formulated based on the respective hypothesis. As an integrated system, we mean a system that takes into consideration four crucial factors connected to each other for the good performance of a small-scale biogas plant: technology, operation management, internal management, and business environment. The adoption of the integrated system is expected to improve the performance of the biodigester in terms of constant and sufficient biogas production combined with sufficient bio-slurry production. In addition, enhancing the management approach of local entrepreneurs in SSA, and analysing the socio-cultural environment around the biogas sector, will represent not only a stable and efficient biogas production but also a successful biogas plant management that can lead to potential business. Considering this hypothesis, it is possible to formulate the following research question:

What are the causes of the poor performance of a small-scale biodigester in Sub-Saharan Africa and how can this performance be improved?

In order to answer this question, first, an evaluation assessment will be developed on the basis of the literature research. In this model, a list of technical, operational, managerial and cultural issues, related with the malfunctions, of small-scale biodigesters are presented. The evaluation assessment can be used to analyse small-scale biogas plants installed in Sub-Saharan Africa, taken as case studies. This will lead to study the business as usual scenarios of the different projects in order to comprehend which factors can affect positively and negatively the biodigester performance, taking into account a technological, operational, managerial and cultural perspective. This analysis will then be used to present recommendations to improve the performance of the current and future biogas projects in Sub-Saharan Africa. This research question can be split into five sub-questions that will enable to answer the main question:

a) *What are the main technical issues that a small-scale biodigester encounters during its lifetime?*

b) *What are the main operational issues that a small-scale biodigester experiences during its lifetime?*

c) *Which internal management behaviours and strategies of local entrepreneurs can be identified in the current SSA context?*

d) *How is the business environment in SSA affecting the entrepreneur's activity in the context of the current biogas sector?*

e) *Which parameters can be used for the development of the evaluation assessment that characterise the performance of small-scale biogas plant and what are their interconnection?*

f) *What recommendations for the performance improvement can be provided on the basis of this analysis?*

1.6. Thesis outline

In the first chapter, the introduction is discussed followed by a brief description of the SSA background, the practical and theoretical significance, the research objective and scope and the research questions.

The research methodology will compose the second chapter and it will include a definition of the sources, the case study development and the analysis method of the case study.

The third chapter will address the literature research. This is represented by the description of the small-scale biogas context in SSA through the analysis of the four main areas that characterise the sector: technology, operation management, internal management and business environment. In addition, an evaluation framework is then developed, containing all the technical, operational, social and cultural parameters that affect the performance of a small-scale biodigester, related to its common malfunctions. With this chapter, the sub-question 'e' will be partially answered because the parameters will be validated in the fourth.

In the fourth chapter, a case study description and analysis will be conducted that takes into account the four main factors, that characterised the integrated system. In addition, the issues evaluation will be addressed in order to analyse the most frequently occurred issues and study the interconnection between the several parameters involved. In the end, the development of the evaluation assessment will be described with all the parameters validated by the case study analysis. In this chapter, sub-questions 'a', 'b', 'c', 'd', and 'e' will be answered.

The fifth chapter will describe the recommendations that should induce to the good performance of small-scale biogas projects in SSA, taking into consideration the main issues that affect it. It is clear that this chapter will answer the sub-question 'f'.

The last chapter will draw the conclusions for the research thesis where the research questions will be answered.

2

Research methodology

After the introduction, this chapter describes the methodology adopted for this thesis research. First, several literature sources used over the entire period of the research will be discussed. Second, the case study design will be explained, including the case study descriptions. Lastly, the method and the structure of the analysis will be articulated.

2.1. Literature

During this thesis research, several literature sources were consulted. These mainly included scientific reports that were obtained through online journals, references consulted in the bibliographies of these scientific documents and thesis researches focused on topics analysed in this research. Additionally, other sources were used such as newspapers and websites. Per each part of the literature research, I have searched some keywords on Google Scholar or just the Google browser that should describe the topic of the part that I wanted to analyse. For example, for the internal management part I have searched keywords like "internal management rural area SSA", "management system SSA company" or "leadership culture Africa", while for the technical part of biogas I have searched "Temperature effect biogas production", or "monitoring system small-scale biogas plant" or "operational parameters biogas production". Not all the material obtained from this research was used as the proper material for literature research, but just the documents that were published by some scientific journals, or thesis research published by important universities. The whole literature research was used to develop the general context of the biogas technology in SSA, to develop the evaluation framework composed of two different tables. The first group of indicators reflects the assessment criteria to analyse the technical and operational characteristics of the biogas plant. The second group of indicators is characterised by cultural institutional parameters that describe already established socio-cultural values, called "dimensions", about the internal management and the business environment that influence the running and maintenance of the biogas system. The latter table is based on literature about entrepreneurship in a different institutional and cultural context and studies established value distinctions of different cultures, in the management literature often called "dimensions", since they are obtained from empirical research which is generalised into overarching concepts. In addition, these dimensions are not as directly visible as the technical and operational parameters, but they are important because they represent necessary preconditions for correct maintenance of the plant.

2.2. Case study design

A case study analysis is developed in this thesis research. The case studies describe five different groups of small-scale biogas plants located in five different countries of the Sub-Saharan Africa (Ghana, Tanzania, Ethiopia, Kenya and South Africa). Four of the total 5 case studies were found through literature (secondary case studies), and they represent four surveys conducted on several small-scale biogas plants that describe both the operational aspects of the maintenance of the plants and the socio-cultural environment around the biogas plants. The last case study is the description of my personal experience in South Africa (primary case study) where I conducted interviews of several expert stakeholders of the biogas technology in the country, such as government officials, CEOs of biogas companies, and professors of the University of Johannesburg, and I visited five small-scale biodigesters. All of the case studies presented a certain amount of failing biogas plants, which permits me to analysed the several issues occurred in these plants. In addition, I chose these case studies because they not only describe the operating and technical performance of the specific biogas plants, but they depict a socio-cultural environment in which these biogas plants were operating. As a result, I could be able to analyse the case studies not only in a technical and operational point of view but also related to the internal management and the business environment. These case studies allowed me to develop the evaluation assessment, through the analysis of the several issues occurred in the biogas plants analysed, that made me able to interpret the several interconnections between the different parameters of the model. The internal validity was improved by comparing the findings of the case studies and the literature study. However, the internal validity of the findings is always limited by the judgement sampling of the several authors [43]. The common aspect of the case study analysed is the performance of small-scale biogas plant in SSA that include the technical, operational efficiency, the internal management of the plant and the business environment around it. Some technical and socio-cultural aspects have already been identified in the literature but through the case study analysis it is possible to demonstrate the relevance of the literature results. This study is conducted mainly for two reasons. First, the literature doesn't analyse the interrelationship between the poor performance of a small biodigester in SSA and the socio-cultural conditions where this technology has to be adopted. This analysis aims to recognise 'how' the technical parameters of the anaerobic digestion are affected by the operational factors that, in their turn, are influenced by the contextual conditions, i.e. internal management and business environment. Second, this research develops an evaluation assessment with a distinction of four main areas that influence the performance of a small-scale biogas plant. It is important to mention that it requires a cross-case analysis to identify either similar or oppose aspects of the biogas plants analysed.

2.2.1. Case study descriptions

Four case studies were obtained from literature research (Kenya, Tanzania, Ethiopia and Ghana), while the other is obtained from my personal experience and collection of data in South Africa. For this reason, the first four case studies are secondary since they are obtained from literature, while the one in South Africa is a primary case study due to a personal investigation and collection of the information. The requirements for being an appropriated case study are mainly two. First, they have to describe the performance and eventually the issues, in terms of biogas production and operational parameters, occurred at one or more small-scale biogas plants (below 50 m^3) located in Sub-Saharan Africa. Second, a description of the socio-cultural context where these biogas plants are operating is necessary to analyse also the internal management and the business environment inside and around the plant respectively. A total of six case studies are collected within total 302 small-scale biogas plants ($< 50m^3$ of digester volume) located in six different SSA countries: Ghana, Tanzania, Kenya, Ethiopia, South Africa and Uganda.

Table 2.1 shows the locations of these biodigesters, as well as the distinction between fully operational and partially/not operational. As 'partially' it is considered as less than half of the maximum biogas production potential of the plant, so less than $0.5m^3$ biogas / m^3 digester.

Location	N. biodigesters	Fully operational	Partially/not operational	Source
Ghana	48	22	26	[8]
Tanzania	12	4	8	[123]
Kenya	176	126	50	[128]
Ethiopia	57	23	34	[34]
South Africa	5	1	4	personal experience in Johannesburg

Table 2.1: Description of the analysed small-scale biogas plants, including the location and the amount of fully and partially/not operational biodigesters

2.3. Case study analysis

The case study analysis is conducted by taking two main steps. First, the case studies are described and analysed taking into consideration the context where the biogas plants are located and the performance of the plants through the four main areas already developed in the literature research. Even if this part is time-consuming, it allows a preliminary analysis of the several parameters that significantly benefit the analysis of the remaining cases and the following analysis. During the case study analysis, it was possible to collect all the issues occurred in the part or not operating biogas plants of the case studies. It was considered the number of biogas plants that were partially or not operating in the case studies as the total amount of valid respondents in the issue evaluation. Some respondents gave more than one issue as the cause of their plants' malfunction, so the total amount of issues declared is higher than the total amount of respondents and biogas plants as well. Also, the issues are categorised per each area that composes the evaluation assessment. In this way, a preliminary analysis of the issues was developed where they were counted and categorised by the four main areas that compose the evaluation assessment.
Second, the ten most occurred issues were evaluated. Through the case study analysis, the several issues described by the authors were motivated by them in terms of which aspects

of the biogas plants had caused that specific issue. As a result, all the issues collected in the reports were motivated by influential factors, both operational and socio-cultural, that could negatively influence the issues. The issues evaluation was conducted from the findings of the case study descriptions, developed by other authors, and the literature research developed in chapter 3. This evaluation included relationships of cause and consequences between the several issues and other factors explained by the case studies. In the end, through the use of the literature research, I was able to directly link the parameters developed in the evaluation framework with the factors that influenced the issues analysed. As a result, the most occurred issues could be categorised into the several parameters, and through them, the connections between the parameters, even from a different area, was depicted. All these connections composed the final evaluation assessment that I primarily developed through the literature research, but in a superficial point of view where all the parameters were isolated from the rest.

To develop appropriate analysis and ultimately the evaluation assessment, an iterative process is conducted. First, the literature research provided the necessary context of biogas in SSA in terms of technical parameters, operational factors, internal management and business environment dimensions. The indicators gathered from this study are used to develop tables that could be used for the case study analysis. The literature research shows that some research gaps on the influence on the biogas performance of socio-cultural factors in terms of internal management and business environment in SSA. Successively, through the empirical data gathered from the case studies the evaluation assessment is validated and developed. A list of all the type of issues presented in the case studies is developed to observe the frequency of each type of issue and then to check which indicators, previously elaborated, are accomplished in terms of technology, operation, internal management and business environment. Taking into account this wide variety of issues, a holistic approach is required to analyse the vast amount of aspects that have to be considered. Structured analysis is necessary and it is already established by following the sections of the literature research and successively the evaluation framework. In this way, it is possible to analyse the interconnections between the several parameters and how they not only influence the biogas performance but also they influence each other.

3

Literature research

In this chapter, the literature research will be given in order to contribute to the body of the research thesis analysing and solving the research questions presented in paragraph 1.5. It will be used as groundwork to develop the case studies analysis and the evaluation assessment that will be used as a means to answer the main research question. First, an overview of the biogas technology dissemination in Sub-Saharan Africa will be given. Second, a description of the biogas product, the anaerobic digestion (AD) process and the most used process technology in SSA for small-scale production is developed in order to give an overview of the technology and product. Third, findings in the literature on the topics concerning the technical and operational parameters that affect the whole biogas production process in SSA will be discussed. This is followed by a description of the main values that characterise the internal management of a biogas plant in SSA. Then, findings on the business environment aspects in SSA will be presented. Lastly, a section on the education level in Africa and its role in the adoption of the biogas technology will be introduced.

3.1. Biogas in Sub-Saharan Africa

Africa represents the most poorly developed region in terms of energy production within the global energy system, in particular, the Sub-Saharan Africa where critical challenges are still presented such as water pollution and access to energy sources. Nowadays, less than 43% of the population in SSA have access to electricity, and nearly 80% of the total are located in rural areas where environmental and economic issues are more emphasised [134]. The need for renewable energy sources from local resources is becoming a crucial factor for its future development. Appropriate and economically feasible technologies that can produce energy as well as regulate the solid waste and water treatment at the same time can be considered as a solution for the African energy sector [76].

Recently, the interest in biogas technology, where biogas is produced through anaerobic digestion of biomass, has increased in SSA due to its capacity to be installed anywhere with the only requests of water and feedstock availability. However, since its first appearance in the 1950s, the adoption of biogas technology has always been very moderate. In 2007, the "Biogas for Better Life - An African Initiative" was launched with the aim of 2 million biogas plant installations by 2020 in Africa through the adoption of investments and business plans [120].

This was the first step towards a homogeneous adoption of biogas in SSA and the establishment in 2009 of the Africa Biogas Partnership Programme (ABPP), between two non-profit organisations (NPO) from the Netherlands, Hivos and the Netherlands Development Organisation (SNV), enhances the diffusion of domestic biogas projects in the whole SSA area, particularly in five SSA countries: Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda [2].

Country	**N. small/medium** ($\leq 100m^3$)	**N. large digesters** ($> 100m^3$)
Botswana	Several	1
Burkina Faso	>30	-
Burundi	>279	-
Egypt	Several	Few
Ethiopia	Several	>1
Ghana	Several	-
Cote D'Ivorie	Several	1
Kenya	>500	-
Lesotho	40	-
Malawi	-	1
Morocco	Several	-
Nigeria	Few	-
Rwanda	Several	Few/Several
Senegal	Several	-
Sudan	>200	-
South Africa	Several	Several
Swaziland	Several	-
Tanzania	>1000	1
Tunisia	>40	-
Uganda	Few	-
Zambia	Few	-
Zimbabwe	>100	1

Table 3.1: Biogas installation in African countries in 2007 (Adapted from [76])

In 2017, the programme enabled the installation of over 50,000 biodigesters, although its goal was to reach 100,000 installations by the same year [1]. In addition, other SSA countries are involved in the adoption of biogas technology such as Benin, Cameroon, Lesotho, Madagascar, Nigeria, Rwanda, Senegal, South Africa, and Zimbabwe.

Table 3.1 shows the number of digesters installed in African countries as of 2007. Naturally, since 2007 the number of installation has increased considerably, but still, several limitations need to be improved in terms of biogas yields and acceptability of the technology.

3.2. Biogas production

In this section, a description of the products of the biogas plant and their application is presented. This is followed by an overview of the anaerobic digestion process that controls the biogas production and composition. Lastly, research on the most typical digester designs developed for small-scale production of biogas in SSA.

3.2.1. Anaerobic digestion process

The anaerobic fermentation is a biological conversion process that starts with complex organic materials that are metabolised into biogas - a gaseous product with high methane content - through the consecutive level of digestion by a different kind of microorganism. Ideally, the process as we can understand from the name has to proceed without air, more precisely oxygen, and neither electron acceptors such as nitrate (NO_3^-) or sulfate (SO_4^{2-}). The anaerobic digestion process is based on the sequence of four main steps:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

In the hydrolysis step, the organic polymers, carbohydrates, proteins and fats are decomposed into smaller fractions such as amino acids, fatty acids, glycerol and sugar. During the acidogenesis stage, specific bacteria transform then the hydrolysis products into shorter derivatives like acetic acid, ammonia, alcohols, hydrogen and carbon dioxide (CO_2). Acetogenesis represents the third step, in which acetic acid is formed from organic acids, along with supplementary ammonia, hydrogen and carbon dioxide. Finally, in the methanogenesis process, specific bacteria (methane bacteria) produce biogas, containing up to 70% methane (CH_4), around 25-50% of CO_2, and a limited amount of hydrogen sulphide (H_2S), molecular hydrogen and siloxane. Figure 3.1 describes in a more simple way the whole biogas process divided by its fours steps already mentioned.

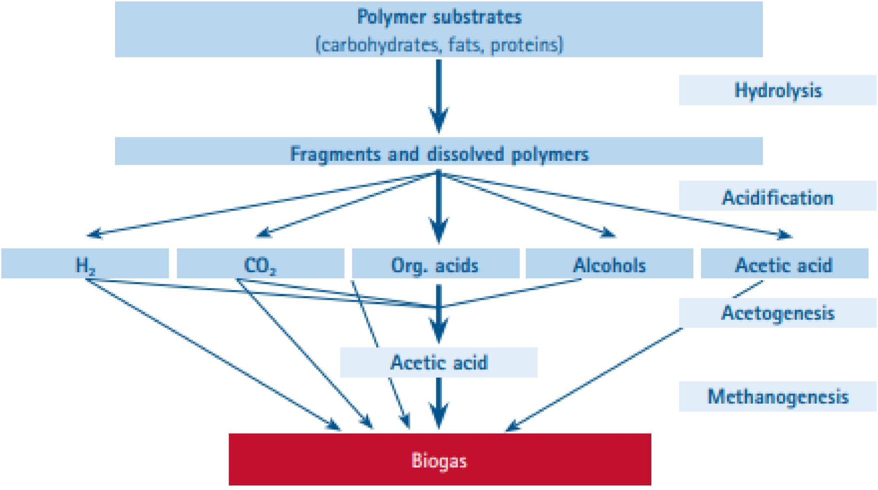


Figure 3.1: Anaerobic fermentation process for the biogas production. Retrieved from: [131]

As we can notice, the digestion process is a complex and highly sensitive mechanism through which biogas is produced under very precise and stable operating conditions. The negative functioning of one of the four processes would affect drastically the other phases and the whole biogas plant would become unstable or even worse disrupted.

In order to achieve the stability of the anaerobic digestion process, a deep awareness of the most important chemical and physical parameters is crucial. These factors are mainly affected by biological activities which influence the physicochemical environment through their substrates and products.

3.2.2. Process technology

Several studies describe a biogas plant as a biological stomach where organic waste (i.e. faecal sludge, animal manure, organic solid waste, brown water, etc.) are transformed into digestate, a fermented and odourless slurry rich in nutrients that can be used as soil fertiliser, and biogas, a methane-rich gas that can be converted into energy. Small-scale biogas plant is composed by an inlet chamber, where organic feedstock is fed together with water in order to reach the optimal TS content (usually is adopted 1:1 as ratio feedstock/water in small biodigester), a biogas digester, which enables the biogas production in a vessel (located in the upper part of the digester, in a floating drum or in a plastic balloon) and an expansion chamber, used as slurry storage from which can be extracted high-quality fertiliser [113].

The interest in domestic biogas digesters has risen worldwide due to his ease of design, construction, operation and maintenance. The feedstock is fed with water in the inlet room until the level of slurry inside the digester reaches around 80% of the total volume, and the slurry in both inlet and outlet has to be homogeneously distributed in order to avoid the production of holes on the surface, that can enhance the entrance of air into the reactor [113]. The gas formed in the digester enhances the mixing of the slurry as it is produced from the fermentation of the latter and then it moves the slurry bed rising up to the gas chamber. Once the level of biogas starts to rise, the pressure inside the digester increases and the slurry is displaced from the bottom upward to the expansion chamber. As the gas is extracted from the reactor, the slurry is induced back to the digester.
The design chosen to construct a small-scale biodigester could be brick dome or prefabricated tanks, below or above the earth and it can be used for households or rural communities, depending on the type of feedstock (i.e. animal manure, food waste, toilet products, etc.), the daily quantity of feedstock, the available area, the characteristic of the land and the kind of usage of the produced biogas. Fixed-dome, floating-dome and bio-bag (or plastic) digester are the most common domestic digester designs used in SSA rural area [113]. They are usually installed in rural schools and local communities since their application is usually for cooking, lighting and sanitation, called as direct use of biogas, instead of electricity generation ([110],[65]).

Fixed-dome digester

This design is represented by a digester, usually brick-constructed or plastic-prefabricated, with a steady gasholder on top of the structure, and a compensation tank, also called "expansion chamber", for the slurry digested. Initial feedstock has to be feed in the reactor until the height reaches the bottom level of the expansion chamber. As gas quantity starts to rise, gas pressure begins to increase pushing the slurry through the output pipeline to the expansion tank [98]. The pressure generated in the digester, thanks to the constant volume

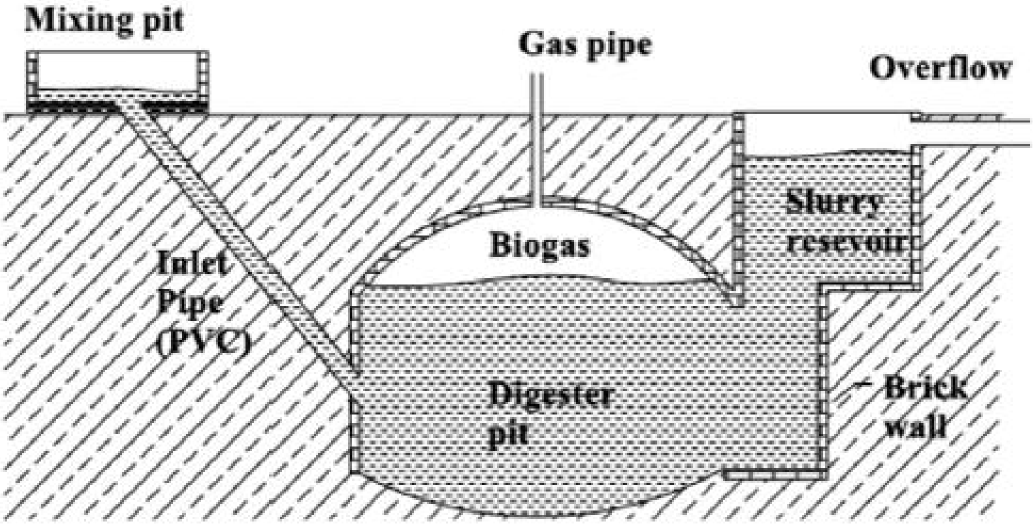


Figure 3.2: Fixed-dome digester design. Retrieved from [116]

of the dome, enables the transportation of the gas produced from the gasholder and the direct application [113]. Once the methane-rich gas is exported, the slurry located in the storage tank is pushed back into the reactor's bed due to the pressure difference produced. The adoption of this design brings both advantages and limitations. An advantage of the fixed-dome digester is his low investment and maintenance cost due to the simple structure and his anti-rust construction material. In addition, this material is considered 10% available in SSA rural areas, making the digester economically feasible for local communities and rural households. Another positive aspect of the fixed-dome digester is that it can be constructed under the ground to protect the digester from the seasonal temperature fluctuations. Although this design needs certainly biogas specialists that can supervise the construction stage, in case of good installation, the digester can have a long lifetime (about 20 years) and it would represent an important benefit for local workforce [24].
However, the adoption of this biogas technology could bring some technical limitations such as heavy biogas leakage due to the constant volume of the digester, that doesn't allow to keep the gas pressure constant once it is extracted, or due to structural issue caused by the material that could be affected by cracking. The majority of project failures for fixed-dome digesters are induced by gas leakage that represents a serious challenge to biogas users since its maintenance requires high technical skills to repair possible cracking. According to several studies, around half of the fixed-dome installations have no more than 3 years of life span [24].

Floating-dome digester

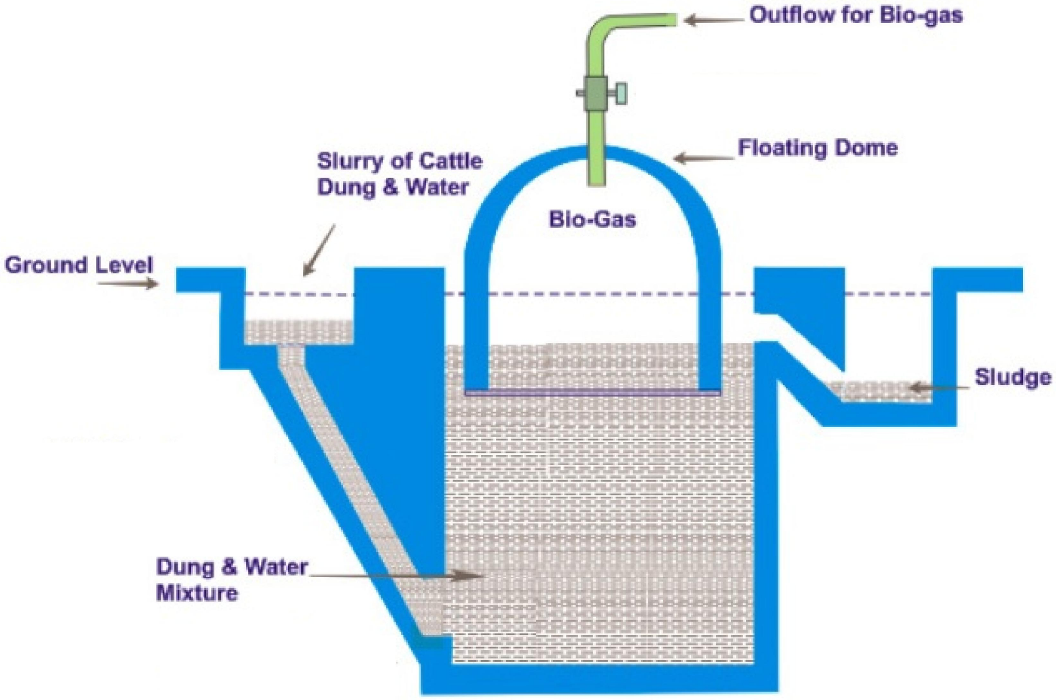


Figure 3.3: Floating-dome digester design. Retrieved from [14]

Floating-dome digester consists of a digester with an inverted floating gasholder which moves depending on the quantity of gas produced. The gasholder can move on a water envelope or directly on the slurry, which both prevents tilting issue of the drum.
Several advantages can be obtained from the adoption of this design. Differently from the fixed-dome, the floating-dome allows to keep the gas pressure constant since the volume of the gasholder changes with the volume (as the pressure) of the biogas, and, once the gas has to be extracted, the drum can apply the right quantity of pressure to push the gas through the pipeline to the households. Moreover, the volume of biogas can be measured easily by observing the height of the floating dome. Another advantage is the ease of installation of the digester and its ability to prevent gas leakage due to the sliding motion [108].
On the other hand, the realisation of this type of digester is quite costly and its maintenance must be constantly monitored by technical experts. Another limitation is the risk of blocking of the gasholder whether can be presented high concentration of fibrous materials in the slurry that could block the movement [98]. Lastly, the adoption of several insulating materials along the digester cannot be realised on this type of design leading to heat losses around the contact area between the drum and the slurry.

Bio-bag digester

Bio-bag digester is composed of a big common plastic (PVC) bag which performs all the fermentation tasks as inlet tank, digester and expansion chamber. Needless to say that the material of the bag has to be durable, elastic and corrosion-resistant. The feedstock and the slurry are respectively fed and stored into water-resistant manholes and the flow is naturally induced by the difference in height of the two tanks.

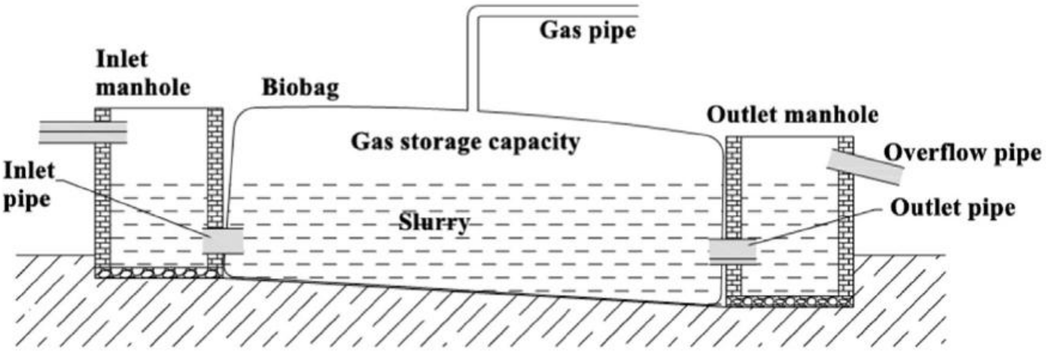


Figure 3.4: Floating-dome digester design. Retrieved from: [98]

Several preventative measures must be followed in order to avoid possible failures. The feedstock, once it is fed within the inlet manhole, has to be refilled with water to avoid the oxygen entrance, harmful for the anaerobic digestion. The slurry height inside the bag has to cover around 66% of the total height in order to leave enough space for the production of biogas. This measurement can be conducted through the observation of the slurry level in the output manhole. Eventually, a pressure pump or a simple weight positioned on top of the plastic digester could provide correct pressure to transport the gas through the pipeline to the rural appliances. As a crucial factor of the reactor efficiency, the fermentation temperature (mesophilic) can be stabilised through the installation of an insulating cover over the entire digester or preheating the input manure in the first manhole.
The main advantages that characterise this design are the ease and the affordability of construction due to the low-cost installation as well as the facility of maintenance. However, the material is very sensitive to the atmospheric weather, temperature and is quite expensive. Another disadvantage is that the output pressure is not high enough to transport the gas produced directly to the households and sometimes gas leakages can occur through the inlet and outlet pipes due to parts not secured properly, hence the digester needs a pressure pump and the installation has to be carried out carefully and precisely. In addition, the manholes are not covered, so the slurry could be more diluted or dried depending on the extreme weather conditions (heavy rain or very hot sun). Lastly, scum formation and residual accumulation are the main limitations for this type of design due to lack of mixing system.

3.3. Assessment Criteria

In this section, the technical and operational factors that characterise the small-scale digester performance found in the literature will be described. The technical indicators will address crucial aspects related to the hardware of the biogas system, such as the plant design and the materials adopted for the construction. The operational indicators will describe fundamental aspects that represent the way the biogas system is operated.

3.3.1. Technical factors affecting performance

The following technical parameters that characterise the small-scale bio-digester performance are described:

- Reactor design
- Design Organic Loading Rate
- Design gas production
- Construction materials

Reactor design

Plant layout

Whatever it is the size and the type of the digester, every biogas plant is composed by the following parts:

- Inlet collecting tank
- Digester
- Gasholder
- Inlet and outlet pipes
- Gas pipe and valves

The fresh manure is typically brought in an inlet collecting tank, before being digested, and it should stay 1-2 days, depending on the type of digester. In the collecting tank, the manure is usually mixed with water, to form the homogeneous substrate that is digested to produce biogas [67]. It is necessary that any stones or sand presented at the bottom of the tank should be removed once the feedstock is introduced to the digester in order to avoid possible blockage of the inlet pipe. In terms of optimal location, the collection tank should be placed in a sunny area to provide natural heat to the feedstock during the mixing with the cold water [107].

The digester, regardless which design is selected, has to meet the following characteristics:

- Water/gas tightness
- Insulation
- Minimum surface area
- Structural stability

The water tightness is important to avoid leakages and soil and groundwater quality hazard. The digester must prevent also biogas leakages and the influx of air through the inlet pipe. The internal digestion temperature must be as much constant as possible, therefore fluctuations need to be minimised both during cold and hot seasons [67]. In addition, the digester structure has to minimise the cost of construction, reducing the ratio surface area/digester volume. A hemispherical structure represents the optimal solution. Lastly, the digester must be load resistance, since it is subjected to two forces: the external active earth pressure and the internal hydrostatic and gas pressure. The spherical shape helps to distribute uniformly all the forces along with the structure, and prevents possible cracks due to peak tensile stresses [107].

Figure 3.5: Masonry construction of a 30 m^3 dome. Retrieved from: [67]

The different gasholder designs are described in the previous section. Floating-drum gasholders are mainly exposed to rubbing and tilting between the drum and the fixed masonry. For gasholder with a volume lower than 5 m^3, a single guide frame is necessary to stabilise the gas drum and prevent this issue, while a double guide is suggested for larger drum [67]. In addition, proper surface protection is required whenever steel is used as a construction material to prevent the formation of rust due to moisture. The fixed-dome gasholders require proper construction workmanship because the typical material used, mortar and concrete, are not gas-tight and they require a really precise work with the addition of coatings [107]. In order to prevent cracks in the gasholder an outer ring of mortar can be applied at the base of the dome to stabilise it, and break/pivot rings can be installed between half and 2/3 of the minimum substrate level to reduce the cracks and distribute all the stress forces [67].

The inlet and outlet pipes should drive the feed and the slurry straight into and out the digester respectively, with a steep angle, in order to allow a natural flow of the fluid. The typical materials used are plastic or concrete, and the diameter of the tube should be 10-

15 cm for liquid feedstock and 20-30 cm for fibrous feedstock. Both of the pipes must be accessible and straight to grant a proper agitation of the substrate into the digester and to eliminate possible blockage through a rod. In addition, the points of penetration into the digester have to be below the minimum slurry level, and they must be isolated with mortar. The points must be located in connection with brick-laying because creating the holes into the digester structure afterwards can create weak points and possible cracks.

More than 60% of the gas leakages are placed in the gas pipes [67]. Biogas contains a high amount of water vapour and hydrogen sulphide. Therefore, ferrous metals cannot be used as a construction material for piping, valves or accessories, since they can react and corrode in a short time. Possible materials for the gas pipes are standard galvanised steel or plastic (PVC or PE), with the latter that must be UV-resistant. During the installation of the gas pipes, special attention is required to make the joints gas-tight, to drain the pipeline, with the adoption of a water trap, and to protect the tube against external mechanical hits.

Volume

The design volume of the biogas plant is the sum of the two main elements of the system: the digester volume and the gas holder volume (m^3). The digester volume represents the maximum volume of the substrate that can be contained in the plant, with an additional safety margin called “dead zone volume”, which is included to prevent feedstock overflow during periods of high biogas production or low biogas utilisation [54]. The gas holder volume represents the maximum amount of biogas that can be contained when the plant reached the max volume of slurry.
The design volume should be measured depending on the total feedstock volume, the available daily amount of manure or waste and water that can be added to the biogas plant (m3/day). The volume of manure produced per day can be calculated multiplying the average manure mass generated by a specific type of animal with the number of each animal owned by the biogas user. The average manure mass generated by each type of animal (kg/day) is described by Table **??**table2.1 Design of Small Scale). This value should be then divided by the density of the specific type of manure. The daily amount of water (L/day) that should be added to the feedstock for the anaerobic digestion can be calculated assuming that 20 L of water is required per each kilogram of manure dry matter in the system for an optimal biogas production [92]. This value should be multiplied by the average manure mass generated by each animal per day, with the number of animals owned and the percentage of dry matter in the dung. However, biogas companies in SSA recommend a 1:1 ratio of water to fresh dung volume to maintain a constant performance of the biodigester but this rate can change depending on the moisture content of the feedstock. In case of fresh cow dung digestion with 25% of TS content, a ratio of 1:1.5 feedstock to water is required for the optimal biogas production [124].

Mechanical stirring

The stirring system is another important aspect to consider for uniform digestion of the feedstock. The mixing step can occur in two different moments: feeding or digestion. The latter is the most effective since it affects directly the digestion process, increasing the rate kinetics of the anaerobic digestion and allowing uniform heating of the reactor. According to Abdullah and Pandebesie [86], the adoption of stirring mechanism, with periods of 8 times and 4 times per day for 5 minutes each, can increase the biogas production of 120% and 70% respectively (with the use of cow manure with TS content of 10%). However, in the fixed dome and floating drum biodigesters (the most used for small-scale biogas plants) is not possible to install a mixing system inside the digester due to their packed design. Inside the digester, the mixing mechanism is done by the biogas release from the digesting substrate, which rises to the top of the dome leading to increase the exposed surface area and to make the digestate more homogeneous [103]. In addition, a pre-stirring of the inlet material during the feeding step improves the performance of the anaerobic digester. In this way, the feedstock is appropriately mixed with water and it is introduced in a homogeneous form inside the digester, improving the anaerobic digestion process and so the biogas production.

Design Organic Loading Rate ($kgVS/(m^3 \cdot d)$)

The Organic Loading Rate (OLR) represents the amount of organic mass, or volatile solids, used per day per unit of volume of the digester ($kgVS/(m^3 \cdot d)$ or $kgCOD/(m^3 \cdot d)$).

$$OLR = \frac{(Q)(C_{VS})}{V_{reactor}} = \frac{C_{VS}}{HRT} \tag{3.1}$$

Where Q is the volumetric flow rate (m^3/d), C_{VS} is the concentration of volatile solids ($kgVS/m^3$) and $V_{reactor}$ is the digester volume (m^3).
According to Rittmann and McCarty [100], for a high-rate anaerobic digestion the OLR should range between 1.6 and 4.8 $kgVSS/(m^3 \cdot d)$, while for a low-rate digestion (no heating and no mixing) the value is 0.5-1.6 $kgVSS/(m^3 \cdot d)$.
According to the literature, an average OLR for a mesophilic agricultural CSTR digester is recommended about 3.0 $kgVS/(m^3 \cdot d)$ [79]. Vesilind [121] in his document measured the optimum range of OLR of 1.9-2.5 $kgVSS/(m^3 \cdot d)$.

Usually, a higher value of OLR, compared to optimal conditions, is applied during the start-up of a digester since bacteria need to readjust the working environment and start the biological activity. During the normal activity, if the digester is fed at too high OLR, organic overload can lead to accumulation of VFA, so a decrease of pH and instability of methanogenic bacteria activity. If the OLR is too low, the biogas production yield is considered too small [80]. The amount of organic component of the feedstock that is used to feed the digester is an important factor for the stability of the fermentation process. However, this aspect depends firmly on the plant type and on the feedstock's composition.

Design gas production (m^3CH_4/day)

The design gas production, measured in m^3CH_4/day, describes the daily volume of methane that a biogas plant is designed to produce under optimal conditions.
The amount of energy that can be obtained from one cubic meter of biogas is proportional to its methane concentration and is around 6 kWh of available energy, the same amount that can be derived from 0.6 litres of fuel oil. Table 3.2 shows typical biogas composition for different type of feedstock.

Component	Agricultural Waste	Landfills	Industrial Waste
Methane (CH_4)	50-80	50-80	50-70
Carbon dioxide (CO_2)	30-50	20-50	30-50
Hydrogen sulphide (H_2S)	0.70	0.10	0.80
Hydrogen (H_2)	0-2	0-5	0-2
Nitrogen (N_2)	0-1	0-3	0-1
Oxygen (O_2)	0-1	0-1	0-1
Carbon monoxide (CO)	0-1	0-1	0-1
Ammonia (NH_3)	Traces	Traces	Traces
Siloxanes	Traces	Traces	Traces
Water (H_2O)	Saturation	Saturation	Saturation

Table 3.2: Average biogas composition (%) for different type of waste. Retrieved from:[22]

The amount of methane depends on several process parameters i.e. feedstock composition, temperature, pH and pressure [70]. Moreover, the changes in the pH of the process can affect the percentage of CO_2 of the biogas.
The biogas composition is an important indicator of process stability, even if the equilibrium between methane and carbon dioxide ratio can be used as the same indicator as well. A reduction in methane composition can predict organic overload in the digester or a H_2 growth can be a process instability indicator. Since the CO_2 solubility is higher than the one of CH_4, the CO_2 content of the gas drops when the HRT is shorter.
However, several studies have demonstrated that methane production (ml-CH_4/day) depends on input loading rate in addition to the process conditions, while methane yield (ml-CH_4/g VS), as biogas production, experiences changes only after the process starts being unstable [3]. For these reasons, it is always recommended to control these parameters simultaneously with early indicators of instability (i.e. alkalinity ratio, temperature, etc.) [31].

Construction materials

In terms of construction materials, the most frequently used are steel, concrete, bricks and plastic. The advantages of using steel vessels are their gas tightness and the ease to construct, with the drawback of possible corrosion, internally due to aggressive acids and externally due to humidity. For these reasons, it requires some type of anti-corrosive coating and regular checking. Concrete vessels are very cheap and they have a very long lifespan (more than 25 years) if they are well maintained, which means installing a gas-tight coat and using lining and seal strips to avoid gas leakages. The use of the masonry construction method with clay bricks cemented concrete or stone blocks is very typical for small-scale digesters due to its very low cost (high material availability) and ease to install. For digesters with a volume larger than 20 m^3, steel supports are suggested [67]. Plastic is mainly used for the construction of balloon gas holders or gas-tight covers. Depending on the type of plastic (PVC, PE, caoutchouc, and GRP) this material can be exposed to degradation, due to aggressive acids in the slurry, mechanical stress and direct irradiation, and to gas leakage. Glass-fibre reinforced plastic (GRP) is the most suitable, since it has a good gas tightness and corrosion resistance, and it is not difficult to repair.

3.3.2. Operational factors affecting performance

The following operational indicators that characterise the small-scale bio-digester performance are described:

- Reactor maintenance
- Actual Organic Loading Rate
- Hydraulic Retention Time
- Solids Retention Time
- Feedstock characteristics
- Reactor temperature

The biogas production process is very sensitive to slight variations of the several technical factors mentioned before in 3.3.1. If one of the four consecutive fermentation steps becomes unstable, as a consequence all the following processes will be influenced negatively, affecting the running of the entire plant. According to several studies [88] [120], small-scale bio-digesters in developing countries used to fail in the first period of production due to several operational issues such as design, maintenance, user needs, feeding system, or availability of materials for the maintenance. According to Nhete and Kellner [84], an estimated 60% of the total biogas plant installed in Africa is not operating due to operational malfunctions. The main reasons of failures involve mismatches between the design calculations and the actual operational indicators, the lack of proper maintenance activity, and the lack of a monitoring system to control the digestion process and the several activities concerned the maintenance of the system.

Identifying possible reasons of process imbalance is crucial to improve the biogas plant performance and to avoid possible future failures. Moreover, this evaluation could actively help to develop a more accurate maintenance service and to diffuse adequate training sessions for the workforce in the biogas plant.

Reactor maintenance

In developing countries, the majority of the biogas utilisation is through the use of biogas stoves, specifically designed for biogas or normal stoves modified for the biogas introduction. In addition, the biogas produced can be used for lighting by biogas lamps, despite their low efficiency (around 3%). The relatively large variation in biogas quality from different plants, in terms of composition, must be taken into consideration, not only for the efficiency of the appliances but also for their maintenance [67]. The main contaminants presented in the biogas are the following:

- Hydrogen sulphide - this compounds can be corrosive when dissolved in water. In addition, during the combustion, this component is converted to sulphur dioxide, which represents a pollutant (at concentration higher than 100 ppm by volume), and sulphuric acids that are strongly corrosive, especially for metal materials.
- Water vapour - it can condense along the gas pipe due to pressure and temperature changes, causing corrosion of appliances and damages to combustion systems by injector wear and filter plugging.

A solution to remove the H_2S from biogas is the use of activated carbon that converts catalytically H_2S into pure elemental sulphur. As soon as the biogas is in contact with the absorbent's surface, the contaminants are captured by the solid carbon from the biogas stream. Usually, around 20-25% of reduction yield of H_2S can be achieved through this method, with the disadvantage of a not easy disposition of caustic carbon along the tubes [90].
Adding a small amount of oxygen can also reduce the level of H_2S below 50 ppm through oxidation with very low operation costs and knowledge [90]. The only drawback of this method is that it requires special attention during the dosing step since the mix can generate an explosion risk. For small-scale biodigesters, desulphurisation is mainly occurred through absorption systems, since they are easy to operate, require low maintenance, low volume, and they are cheaper compared with the other technologies [90].

Due to pressure or temperature changes along the gas pipes, the water vapour presented in the biogas condensates inevitably in the piping system. Moreover, the water can react with H_2S of biogas and generate corrosion to metals. Ideally, the gas pipe should have a sufficient slope (not lower than 1%) to allows a free flow of the condensed water back to the digester. Practically, a water trap should be installed at the lowest point of the pipe. There are two types of water traps: automatic or manual. The first empties itself, without requesting a constant monitoring [128]. However, the investment cost is higher than the manual and it requires a skilled technician to install it. For small-scale biodigesters, especially located in rural area, the manual water trap is the most used, since it is easy to install and cheaper than the automatic one [128]. A simple empty water bottle can be put in the lowest point of the gas pipe in order to collect the condensed water. The only drawback is it requires regular maintenance to be emptied, otherwise, the blockage of the piping system can occur [67].

Actual Organic Loading Rate ($kgVSm^{-3}d^{-1}$)

One of the major factors of process instability is the variations in the amount of feedstock introduced every day in the biodigester during the system operating lifetime. The actual organic loading rate depends on the quantity and on the type of feedstock introduced into the digester because the level of biochemical activity during the anaerobic digestion is determined by the type of feedstock [6]. Generally, an increase of the OLR may lead to higher biogas production, due to an increase in the kinetic rate. During the digestion step, the production of ammonia, from the degradation of protein, tends to increase the pH value, counteracting the fall of pH due to the volatile fatty acids (VFA) formation [109]. However, an excess of the OLR can lead to a volatile fatty acids accumulation in the digester, which results in a fast drop of the pH value and, in turn, in a methanogenic microorganisms inhibition [95]. Considerable deviation on the daily organic loading rate can affect negatively the amount of biogas produced, that can reach even the disruption if the feeding is interrupted for some days depending on the type of feedstock introduced [40]. In practical, acetate and fatty acids produced during the digestion tend to lower the pH value, while the ion bicarbonate of the carbon dioxide and the ammonia contribute to the so-called buffer capacity, the resistance to pH variations. This resistance is quantified by the amount of strong acid (or alkali) added to a solution to cause a change in the pH [57]. For such reasons, it is necessary to record the feed input to the biogas plant. This can be accomplished by an automatic feeding system equipped with weighing cells and data loggers for large-scale production, or by daily numbers of shovel loads for small-scale and less complex biogas plants [31]. Moreover, the volatile solids degradation rate is affected by the change of temperature inside the digester. An increase of the operational temperature induces to a higher degradation efficiency of the VS leading to a higher specific biogas production per unit of VS. This aspect can be explained by faster hydrolysis of the complex organic matter at a higher temperature, which makes their degradation easier for the anaerobic bacteria. As a result, a lower OLR can occur for temperature above the optimal condition, and vice versa [109].

The daily amount of feedstock required for a small-scale biogas plant depends on the VS concentration (% on mass) and the biogas yield (m^3/tVS) of the feedstock, and the total biogas required to meet the useful energy necessary for the users (m^3/day). The VS content of the several types of feedstock is described in Table 3.4. The biogas yield is dependent as well on the VS content in the organic residues. Table 3.3 shows the different biogas production potentials for several types of feedstock.

Feedstock	**Biogas yield** [$m^3 t^{-1} VS$]	**Reference**
Pig slurry	380	[112]
Cow slurry	150-470	[112]
Chicken slurry	130	[112]
Human feces	380	[101]
Rice straw	500	[112]

Table 3.3: Biogas yield from different types of feedstock in Sub-Saharan Africa.

The total biogas required is directly proportional to the total useful energy required for cooking and lighting from the user of the biogas plant. According to Rupf et al. [104], a standard household in SSA spends an average of 32.9 h in cooking and 51 h of lighting per week, which is translated in terms of biogas consumed to 16.1 m^3 and 7.7 m^3 per week respectively. Tucho et al. [117] estimate an energy requirement for cooking of a standard household with 6 members of 6 GJ of useful energy per year, which is translated in terms of biogas to 15.2 m^3 per week (considering 21 MJ/m^3 as calorific value of the biogas and 60% of efficiency of the biogas stove).

Hydraulic Retention Time

The amount of time spent by the feedstock into the digester is called hydraulic retention time (HRT). The calculation of this parameter can be conducted very easily:

$$HRT(day) = V_{digester}/V_{input} \tag{3.2}$$

Where $V_{digester}$ is the total reactor volume (m^3) and V_{input} is the total daily input (feedstock + water) that is fed in the digester (m^3/day) [29]. It is an important parameter because it determines how much time the substrate and specific constituents targeted for the degradation, will spend with the biomass inside the digester. As most of the digesters in SSA are continuous flow stirred tank reactors (CSTR), which means that the output composition is identical to the composition of the digestate inside the digester, the HRT can be considered equal to the microbiological retention time, also called solid retention time (SRT) [29]. The SRT represents the ratio between the active biomass in the system (m^3) and the production rate of active biomass (m^3/day).
Depending on the temperature regime of the bacteria activity, the design of the digester has to consider a sufficient HRT to enhance the volatile solids degradation [103]. Depending on the type of feedstock, at temperatures close to 30°C, a retention time between 20 and 60 days is recommended [41].

Process parameters are altered in case of an evident change in HRT: if the hydraulic retention time is too low, hydraulic overload could occur leading to gradually decrease the anaerobic bacteria concentration inside the system, which means that an imbalance between acidogens and methanogens occurs. This imbalance is induced by an accumulation of VFA, which induces the inhibition of methanogenesis since it increases the generation time of methanogenesis bacteria washing out the micro-organisms present in the digester [31]. In case of a too high HRT, biogas production yield (Nm^3 biogas per unit of digester volume) could decrease significantly in favour of higher digestate production [29]. Depending on the design of the digester, this value can be fixed in order to have a constant biogas production.

Solid Retention Time

The Solids Retention Time (SRT) is defined as "the mass of organisms in the reactor divided by the mass of organisms removed from the system each day" [100]. This factor is described by the following equation:

$$SRT(day) = \frac{active biomass in the system}{outflow rate of active biomass} = \frac{V \cdot X}{Q_w \cdot X_w} \tag{3.3}$$

Where V is the reactor volume (m^3), X is the bacteria concentration in reactor (mg/L), Q_w is the outflow rate from the reactor (m^3/day), and X_w is the bacteria concentration in the outflow (mg/L).
In case of too low SRT, an organism washout can occur, while a too high SRT can lead to a nutrient-limited reactor. SRT is equal to HRT when there is no solids outflow from the

reactor [121]. An increase of the SRT drives to a higher level of completion of the digestion process, a lower sludge production, which results in a higher biogas production [100]. According to Rittmann & McCarty [100], the minimum SRT for a Continuous-flow Stirred Tank Reactor (CSTR), that operates in anaerobic conditions, is around 10 days.

Feedstock characteristics

In case of daily almost similar feedstock (e.g. animal manure) the quality control is not necessary, but where a large mixture of different feedstock is applied, a characterisation of the daily input is important [31].
Different type of feedstock can vary significantly in composition, homogeneity, and biodegradability. Pig and cow dungs are characterised by a dry matter contents between 3 and 12%, while the chicken manure contains in the range of 10-30% [130]. Other agricultural wastes can vary their dry matter content widely.
Another important characteristic is the nutrient capacity of the feedstock for the optimal microbial biodegradation process. An important parameter is the C:N ratio that can vary in a large range between 6 (animal substrates) and above 500 (wood materials). According to Steffen et al. [112], an optimal value of C:N ratio recommended is 100:5.
Another parameter is the total Kjeldahl nitrogen (TKN) which represents the nitrogen content of the feedstock. The use of nitrogen-rich feedstock in an anaerobic digester can be considered as a serious issue for the running of the biogas plant. The degradation of this type of feedstock leads to the production of ammonium nitrogen ($NH_4 - N$) through the two species ammonium ions (NH_4^+) and free ammonia ($NH_{3(aq)}$), where the latter concentration increases at higher pH or fermentation temperature. The accumulation of free ammonia represents one of the main reason of inhibition since it cannot be synthesised by the bacteria and it will contribute to the process instability.
Several studies describe the concentration limits of ammonium nitrogen required for the feedstock but their different values show the difficulty to define that limits due to their strong dependency to the feedstock composition and bacteria adaptability to ammonia [16] [23] [32].
The water content of the substrate is fundamental for an optimal anaerobic digestion process. This value can vary due to different type of feedstock, the change of atmospheric conditions (weather, seasons, etc.) or just different operational activities (dilution, dung and water collection, etc.). The optimum performance of small-scale digesters is achieved with a solid content of 6-10% of the feedstock [92]. If the feedstock does not meet the desired solid content of the inlet, a sufficient amount of water has to be added to reach the optimum condition for the anaerobic digestion process. The high water content of the inlet influences the digestate volume, and also it increases the amount of heat required per m^3 of feedstock in order to reach the operational temperature. However, high TS content of the substrate can drastically affect the fluid dynamics of the digestate and it can cause process failures due to a poor mixing system, pipe blockages, clogging and scum formation.
The last important aspect of the feedstock is the concentration of organic molecules like proteins, fats and carbohydrates due to the formation of Volatile Fatty Acids (VFA) for the degradation of the former during the first stages of anaerobic digestion. In particular, a high VFA formation can be determined by a high fat content, while high protein content leads to an increase of ammonia formation.
These factors influence negatively the alkalinity, so the stability, of the system in case of

out-of-range values. A drop of the alkalinity can be caused by several factors such as the accumulation of organic acids in the digestate due to the low conversion rate of these to methane by methanogenic bacteria, slow discharge of organic acids to the AD, or the presence of wastes that block the methane conversion in the digester[125]. The high concentration of proteinaceous wastes leads to an increase in the feed rate of proteins within the sludge and an increase of the alkalinity due to its degradation [125]. The absence of alkali compounds or their precursors in the feed induces the addition of alkalinity to the digester to stabilise the pH. The quantity of alkalinity to be added should be in proportion to the organic acid production capacity of the feedstock (1 g of volatile acids per gram of volatile solids) [125].

Reactor temperature

The biogas yield and its quality is highly influenced by the operating temperature during the anaerobic digestion process. The microorganisms involved in the biodegradation process (in particular during the methanogenic step) can be classified into three types:

- Thermophiles: it operates at thermophilic digestion conditions with a temperature higher than 45°C;
- Mesophiles: it operates at mesophilic digestion conditions with a temperature range between 20°C and 45°C
- Psychrophiles: it operates at psychrophilic digestion conditions with a temperature lower than 20°C

In practice, environmental alterations such as radical rises (especially during the summer season) or drops (during the winter season) in temperature, may affect all the process parameters and the system needs a long period to adapt to the new conditions. Solid-state digesters with long SRT (HRT), will not rapidly change in temperature. In addition, the growth and metabolism of the microorganisms is strongly dependent on the internal temperature. However, a proper rector design should take the seasonal temperature variations into account and counterbalance this change with the amount of OLR. According to Nekhubvi and Tinarwo [82], the overall production yield ($L_{CH_4}/m^3_{digester} \cdot day$) can be expressed by the following equation:

$$\gamma = \left(\frac{B_0 S_0}{HRT}\right)\left(1 - \frac{k}{HRT * \mu_m - 1 + k}\right) \tag{3.4}$$

where B_0 is the biochemical methane potential (L_{CH_4}/kg_{VS}) , S_0 is the organic concentration - VS - in the feedstock (g_{VS}/kg), HRT is the hydraulic retention time (day), μ_m is the maximum specific growth rate of the feedstock's microorganisms (day^{-1}), and k is the kinetic constant [82]. The maximum specific growth rate of microorganisms can be described by the equation:

$$\mu_m = 0.6 + 0.0039 e^{0.11881 \cdot T_s} \tag{3.5}$$

where T_s represents the bio-slurry temperature. Moreover, the kinetic constant is defined with the equation:

$$k = 0.6 + 0.020e^{0.051 \cdot S_0} \tag{3.6}$$

These two equations are not generic but specific for the cow dung with temperature ranging in psychrotrophic condition. Average value on total solid and inlet volatile solids concentration (S_0) are provided from the literature as described in table 3.4.

Feedstock	Total Solids TS [%]	Volatile Solids [% of TS]	Retention Time [d]	Reference
Pig slurry	3-8	70-80	20-40	[112]
Cow slurry	5-12	75-85	20-30	[112]
Chicken slurry	10-30	70-80	> 30	[112]
Human feces	25	89	-	[101]
Garden wastes	60-70	90	8-30	[112]
Fruit wastes	15-20	75	8-20	[112]
Food remains	10	80	10-20	[112]

Table 3.4: Chemical and operation parameters of the most typical feedstock for small-scale biodigesters.

Higher operating temperatures induce a higher bacterial activity, and so a higher production of methane for biogas, with the drawback of consuming a massive quantity of energy to reach the temperature. Figure 3.6 shows the growth rate of methanogenic microorganisms at different temperature regimes.

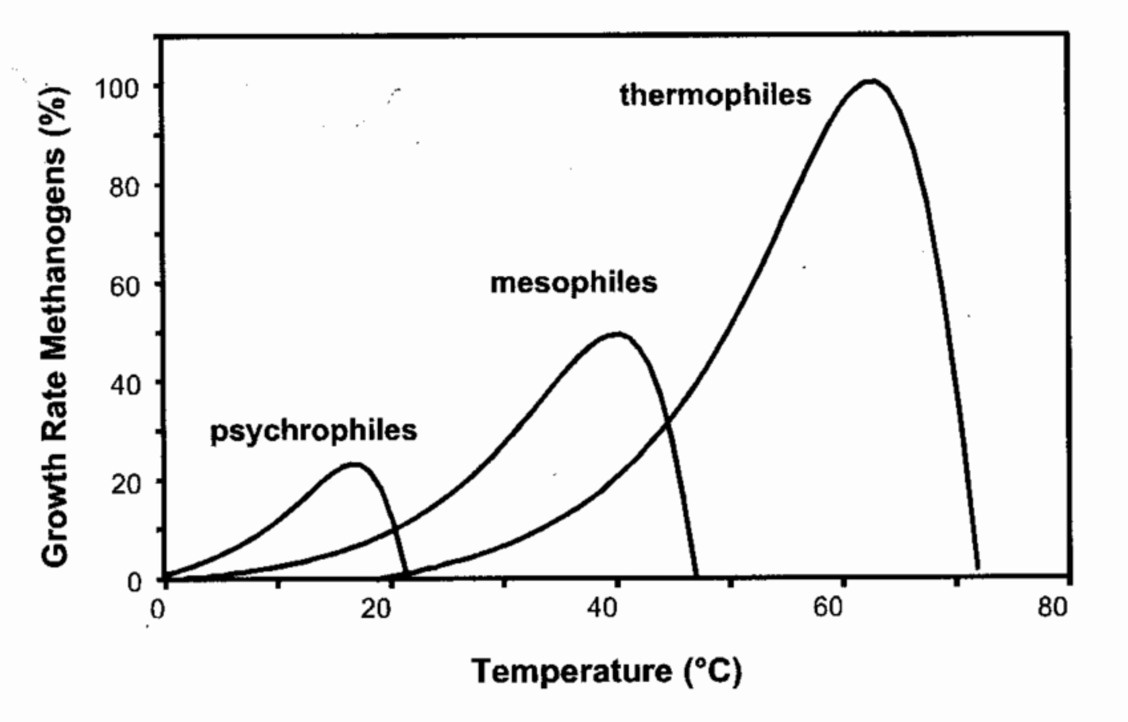


Figure 3.6: The methanogenic bacteria growth rate depending on the temperature regimes. Retrieved from:[109]

For small-scale biodigesters in SSA is sufficient to maintain constant the digestion process without any heating system due to the typical warm climate and the lack of capital among the local owners [110]. For this reason, it is possible to consider general biogas installations in SSA based on psychrophilic or mesophilic anaerobic digestion. In addition, the thermophilic bacteria during the methanogenic process shows a higher sensitivity in terms of biogas yield for the temperature fluctuations (for +/-1 °C) than the mesophilic bacteria that can resist temperature changes of +/- 3 °C [109]. According to Wang et al. [129], comparing the maximum biogas production at 35°C, a decrease of temperature to 30°C, 25°C and 20 °C would lead to a decrease on biogas production by around 22.4%, 36.2% and 70.4% respectively.

Keeping the temperature constant is a crucial factor for the stability of the entire biogas production process since it affects the microbiological activity inside the digester.
Methanogenesis stage, in particular, is the most sensible to the temperature and it limits the fermentation process that needs to keep the temperature constant within a maximum of ±1/3 °C [131].

3.4. Critical institutional parameters

In this section, a substantial amount of abstract parameters about entrepreneurship in the SSA context will be described. These concepts are based on the literature about different institutional and cultural context than the biogas context and they refer to established value distinctions of different cultures, in the business and management literature often called "dimensions", that are derived from empirical research which is generalised into overarching concepts. The internal management dimensions will address crucial aspects related to the people involved in the management of the biogas plants, how they operate, how they are managed by the biogas owners.

The business environment dimensions will describe the set of social codes that characterise the environment where entrepreneurs or businessman have to operate.

3.4.1. Internal management in Sub-Saharan Africa

In the previous section, the technical and operational parameters of a biogas plant performance were discussed. This paragraph will focus on the theories and findings in the literature that forms the basis of the internal management in SSA. First, the distinction between hierarchical and egalitarian system is described. Then, ’collectivism vs individualism’ value is developed. The third dimension analysed in this section is ’initiative against traditionalism’. Successively, the contrast between universalism and particularism is presented. The ’status by position and by achievement’ is the fifth dimension to consider. Lastly, time management is analysed in order to have a complete overview of all the aspects.

Hierarchy vs egalitarianism

According to Katz and Kahn [59], the term "control" is defined as: "a basis of compliance to produce the coordinated patterns of social behaviour known as organisations". The awareness of this definition allows us to establish a closer relationship between culture and the internal management style. It is important to take into account that different management approaches are influenced by the goal and the local environment around the firm [56]. Sub-Saharan Africa has experienced an essential cultural evolution in terms of management control. The first leadership pattern observed by scholars was the one known as *Bantu*, interdependent and hierarchical societies composed by nomadic tribes. Successively, these rural communities were substituted by the colonial governments characterised by rapid urbanisation and the disrupt of the traditional agricultural rural communities. Then the post-colonial power process came later on where governments attempted to relocate the power, jobs and capital to the black Africans [85].

Nowadays, the management system presents the aspect of high power-distance between the owner or manager and the ordinary workers. A hierarchical, heavily bureaucratic and vertical controlled form of power is very common in SSA where the decisions are taken by the boss which imposes tasks from the top to the bottom without discussing the workers’ opinions and ideas, as Kiggundu explained in his study [64].

Jackson et al. in their article defined the typical management style in SSA with the term "indigenous". As indigenous management, they consider local management strategies that reflect knowledge and behaviours of the local context and local communities [56]. According to Blunt and Jones [17], the behaviour adopted by the so-called *indigenous* managers is more authoritative than the power system described by Kiggundu. The leadership style in Africa is depicted as highly centralised with a bureaucratic impedance to change since the management concern is focused mainly on the control effectiveness over the subordinates rather than the organisational efficiency.

Vlieger observed in his research that the relationships between the manager and the employee are characterised by a sort of egalitarianism where there is open dialogue within the same ethnic or age group [122]. The main drawback for a too-high hierarchical system is represented by the lack of professional judgement of the workers. If the employee deal with complex technology, a professional and independent behaviour among them is necessary to maintain a good performance of the technology. This aspect becomes crucial when the workers are not able to develop individual opinions of their own due to a strong reliance on the boss decisions [**?**]. Finally, not only a hierarchical but also paternalistic authority seems to prevail in SSA where the manager provides a form of protection or favour to his workers, requiring some kind of loyalty in return [56]. In a paternalistic management style, the success of a business is directly related to the benefit obtained by the dominant in-group [56].

Collectivism vs individualism

Collectivism is considered one of the main values that discern African management style from the Western one. This means that group interest comes often before the individual one [43]. Traditionally, the leader of the group always necessitated consensus when a decision should have been taken, and this was achieved through long reconciliation and discussion. However, the lack of communication between superiors and subordinates is often present due to a hierarchical society between age or status groups [11]. This aspect affects negatively the workers' attitude as they are afraid to express their opinion or unwilling to develop their point of view, which hinders their creativity and ambitions. In this way, workers, that are identified within the group, don't feel responsible and they will not think outside the group or share creative ideas that could be in contrast with the decision of the superior [122]. Also, this closed in-group mentality limits the trust to people of the same group. This personalised trust leads to cooperation and group mentality inside the group but at the same time leads to division and competition with the out-group. Fülöp and Büki [39] demonstrate, in their research, how in-group relations reflect collaboration while out-group connections are characterised by a negative competition which becomes a limitation for the productiveness of each.

This type of collectivism differs from the team spirit collectivism. In a group characterised by teamwork, people are willing to express different opinions, creating sometimes also discussions, with the common goal to contribute to the success of the company/group [68]. Teamwork differs from the individual collectivism also due to the cooperation between people or groups that are different either in language, religion, clan or just prospective because they contribute to the team [68]. Paternalism and willingness to satisfy the interests of few employees from the dominant management group, instead of a sense of duty to a wider out-group community, describe the difference between collectivism and team spirit [43].

Some authors have argued that this "African" collectivist culture represents a barrier for the success of an entrepreneurial activity [30]. In a Western point of view of entrepreneurship, the latter is seen as highly individualistic characterised by an open dialogue between in-group people based on equal social status [68]. Individuals are freer to take own decisions or at least to express their own ideas because they are not bounded to the in-group. However, Bhawuk and Udas concluded in their article that the individualistic approach for responsibility and creativity is as much important as the collectivistic capability to gather people together and promote obligation and sacrifice [13]. This theory is supported also by Morris et al. with their findings that suggest that successful entrepreneurship is characterised by a balanced mix of individualism and collectivism where employees value both group and personal welfare [75]. According to Jackson et al. [56], SMEs reflects the in-group collective interest but they also provide service and benefits to the out-group community through employment.

Initiative vs traditionalism

Another important factor that affects the performance of a plant or a company is the workers capacity to take initiative. This aptitude makes the people faced up to their responsibilities for change and future. Uncertainty and fear to fail are the main sensations that people have to confront in case of leaving their comfort zone. Uncertainty avoidance represents the adversity to take unauthorised initiatives due to a too high risk of going against the group [68]. The one who usually takes initiative and aims to change does also put himself outside the group because this implies also tensions and discussions between members of the group. Leaving the group means, in a society stick to tradition, to question their own loyalty towards the group. The main consequence of this cultural characteristic is that SSA societies tend to avoid uncertainty and risks [51]. For instance, Saleh concluded that Kenyans prefer to accept decisions taken from the top without discussing it instead of seeking for change or discussing their own ideas [106]. In contrast with the African tradition, the Western tradition is currently characterised by the attitude of pursuing change and taking initiative in favour of a "new" that is more attractive and reasonable than tradition [68]. Boermansa and Willebrand found that an out-of-the-box thinking attitude is required by entrepreneurs in Tanzania to improve their business and lead to innovation [18].

Universalism vs particularism

The internal relationships of people with friends, employees, customers or bosses are characterised by another value orientation that influences the way of doing business and managing the group: universalism versus particularism. The universalist culture legitimates a set of rules that judge people's behaviours regardless of personal relationships or circumstances. In contrast to the rule-based system, the particularist culture tend to question or disobey to these rules in order to protect or sustain personal relationships when they are challenged by them [48]. In management terms, particularist people are focused more on particular circumstances with their family or friendship ties. They prefer the diffusion of informal networks where personalised trust, private agreements and subjective treatments occur typically. In daily dynamics, sometimes the production of a plant can be subordinated by the personal motivations of the owner such as a friendly visit or a family trip. The consequence is the employee expectation that the management can make exceptions because of the personal relationship and discontinuity of production [69]. In case of universalist management style, the manager or the boss usually imposes a set of rules that have to be respected by everyone, without any personal exceptions, and the people that are judged by these rules are treated in equal way [48].

In societies where rule of law is not strictly applied institutionally, the particularist system is dominant with ethnic or aged or status or patronage relationships that prevail the equal treatment by the government. After the decolonisation, African society experienced some issues in terms of traditional institutions and a modern set of rules. The development of large-scale societies in SSA led the establishment of the coalition of tribal elites or ethnic group that prevented the introduction of an open civil society controlled by a centralised government bureaucracy [68]. This situation was the consequence of an unavoidable process generated by the increase of scale and a still in-group oriented and particularist system characterised by a lack of trust between different groups.

However, the success of a business in SSA is not directly connected with the adoption of a universalist set of rules. Sometimes even the universalist rules application cannot comprehend a particular concern because the reality is constituted by infinite circumstances much more complex than rules pretend to objectify [48]. Kroesen and Rozendaal described in their article an interesting example of a unique business model of the Ubuntu Company in South Africa that embraces both traditional and modern values [69]. The model shows an aspect of particularism as well as universalism. On one hand, the South African culture presents a particularist attitude made by personalised trust and personal relations between in-group members, on the other hand, the Ubuntu Company adopted a universalist regulation with a strong desire of equality described by clear employee rights hung up in the production hall [69].

Status by position vs by achievement

Status, as position fulfilled in a particular social group, can be obtained from position or achievement. Status by position is represented by caste, patronage, family ties or traditional loyalties. Status by achievement is obtained from personal skills and accomplishments [68]. The relationship between the manager or the owner of the plant and its workers as well as the labour attitude are related to this value. Typically, in traditional societies, the person that performs the highest status position in the group has to make decisions without doing hard work due to the power distance between different status levels. People aim to upgrade their status building stronger relationships with who owns a higher status such as the boss, instead of meet their targets at work because the latter doesn't benefit their status [68]. In this type of societies older people, males, skilled people in the project management or technology are admired 'naturally' due to their status and the number of subordinates that show affection and loyalty, instead of for their performance on tasks or functions [48].

This attitude towards labour changed drastically with the Protestantism that transformed the work as action from a matter of disrespect to a value. The status doesn't represent anymore something that people deserved before they actually earn it, but people are evaluated by what they achieved and how they perform the specific task. In this way, all the members of a company or a group have a functional role and their relationship are functionally specific due to the role acquired by each member [48].

Planning vs synchronic time management

Time management can be described as the planning procedure to organise personal time between specific tasks. The sequential person tends to schedule everything (event, deadline, personal meeting etc.) very precisely, with an appropriate division between time slots.

In a sequential system, the work is planned in advance with precise time slots per each task that conduce to the established goal[48]. The synchronic method, however, requires that people handle several parallel activities at the same time. Even if the final goal for both sequential and synchronic time management is the same, such as the achievement of the task, the latter takes into account different interchangeable steps to reach it. For a synchronic person, the personal relationships overrule the sequential structure of the time [48].

In SSA entrepreneurship culture there are different "time wasters" due to lack of managerial knowledge such as scarce planning, paying attention to many things at some time, overlooking or underestimating deadlines, counterproductive meetings, restrained communication due to solid power-distance relationships and not planned deadlines for the job tasks [115]. In addition, a professional and independent attitude of the workforce is characterised by the maintaining of a work constancy and commitment also in case of owner's absence or lack of orders from him [55]. Small-medium enterprises should focus more on productivity assessment, time management, employees motivation and creativity, instead of aim attention at keeping their control structure as much centralised as possible. According to Chachage and Ngulube [83], management culture in Tanzania shows some limitations which include lack of a proper system of record, neither digital or paper-based, poor compliance, lack of incentive support, technology standards and professional attitude among the labour force.

On the other hand, to develop efficient time management, responsible and skilled workers are necessary since they need to understand the relevance of a proper job planning and be able to handle a suitable system of record. Local entrepreneurs should invest time in developing professional attitude among their employees because of saving it more for a continuous, useless and time-consuming guidance [83].

3.4.2. Business environment

In the last paragraph, the internal management level of the evaluation framework has been discussed. In this paragraph, we are going to analyse the cultural dimensions that characterise the environment around the business of the biogas in SSA. This part starts with the description of the role of the government and institutions in SSA for the adoption of biogas technology. This is followed by the distinction between horizontal and vertical networks in the SSA society. Finally, the 'distrust vs anonymous trust' value is then analysed.

Governance and institutional environment

In this paragraph, the level of governance above the level of internal management is described. The creation and maintenance of a good relationship with government authorities is an important factor for the proper business management of a company or a small biogas plant. In a society where vertical networks of clientelism and patronage are still dominant, obtaining the right contacts and being accepted by the appropriate vertical networks are considered the fastest and easiest way to influence the government bureaucracy to get licences, tax regulations or just cooperation. In this way, investment in terms of time and money are necessary.

According to Eifert et al. [33], doing business in Africa through the access of vertical networks is estimated 20-30% more expensive than in other countries, compared with an average of 15% in other developing countries. The enforcement of equal access to the government bureaucracy, of rule of law, unique regulations and contracts by the government authorities would make cooperation and anonymous trustless complicated and expensive [60]. In addition, a confused and unclear regulatory framework, lack of communication and cooperation between government departments lead to the strengthening of vertical networks [45]. The confusion and the lack of transparency allow the informal networks to dominate the business environment where people concede favours to friends or in-group members and reject the cooperation with outsiders. In terms of the regulatory framework, a clear and unique standardisation of the biogas technology to a single appropriate design is necessary for the control of the biogas performance using the same quality standards and to allow a large number of competing companies, in terms of construction, maintenance and installation, to enter the market [78].

Another important aspect influenced by the government is the technical and management education among biogas owners that can be provided through promoting integrated biogas initiatives [135]. According to Nyagabona and Olomi [87], the national government should focus on promoting awareness campaigns by media, turning their policies into actions, and developing practical programmes and institutional frameworks to support biogas activities. An interesting example is "Biogas for Better Life", an African initiative in collaboration with SNV (Netherlands) and KfW (Germany) that covers a large number of countries in SSA such as Benin, Burkina Faso, Cameron, Ethiopia, Ghana, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Niger, Rwanda, Senegal, Togo, Uganda, Zambia and Gambia. The initiative aims to succeed in the implementation of biogas technology in Africa as a market-oriented partnership between governments, private sector actors, civil society agents and international partners, with the specific target of the installation of 2 million biogas plants by 2020 [120]. The Biogas Initiative set also several guidelines that every national biogas programmes should take into account. A sustainable programme should consider different aspects for the development of biogas technology: institutional, social, economic, cultural, private sector participation, civil society and development agents [120].

Horizontal vs vertical networks

Despite the big social and economic transformation that the Sub-Saharan Africa economy experienced during these decades in terms of the family network, education and state institutions, the patrimonial system of vertical network, clientelism, patronage and compartmentalisation are still present [61]. This type of society is described by Putnam [97] as consisting of vertical networks in opposition to horizontal networks. In the vertical networks, group members build their relationship based on the aim of acquiring status in the individual competition with others and on the pursuit of personal interest, for instance when local owners provide a service and favours to their clients in return for loyalty and help. Therefore, one of the big issue in running a small business, or even a biogas plant, in this kind of societies (especially in developing countries) is to create cooperation and open networks of trust and honesty [47]. The trust and responsibility among citizens are always limited to the family or the clientelistic networks [52]. That means that people need to invest not only money but also the time in order to build trust and cooperation with future partners or customers. However, Putnam explains that such systems are preserved as their members are afraid to be excluded from networks they belong, and as rational survival strategy they don't want to lose their bonds, even if they recognise the drawbacks of the vertical network system [97].

On the other hand, horizontal networks are characterised by a well-functioning civil society, where members are free to pass from one association to another without losing their social status and their relationships are established on anonymous trust, cooperation and exchanges for mutual gain. In such social systems, local owners are necessary to guide their workers towards the good performance of the biodigester, but with a conscience of being trustworthy and without vertical exploitation [97].Finally, members of this system have usually equal rights and commitments.

Distrust vs anonymous trust

In the SSA society, the external relationships, with partners or suppliers or customers, are usually seen in an instrumental way due to a strong in-group mentality and a weak out-group commitment [69]. In this kind of environment, anonymous trust between people from different groups is not immediately available but it requires important investment to build good relationships and trust and to maintain them in the future. Family or "vertical networks" usually limit the trust and the commitments to a merely bond of friendship or just a result of a patrimonial system where the boss or someone in a powerful position dispenses favours among their partners or clients in return for their obligation and support [69]. Moreover, building trust for African business is considered not only an investment of time and energy but also of real money. In an environment where vertical network and lack of anonymous trust are present if a member of a vertical network needs cooperation from "outside", he/she requires a person that can function as a bridge between those groups and also the guarantee to the other person in economic terms [63] [69]. The creation of cooperation and open networks of trust and commitment is one of the biggest problems in doing business in developing countries.

According to Kelsall [62], the lack of anonymous trust can be considered a consequence of the presence of the informal network that is generated to meet a traditional necessity. These type of networks needs to be hidden outside the traditional group, as they concern illegal activities and it is very dangerous to believe in the outsiders' loyalty. As Hofstede explained [50], in the SSA's society there is a strong sense of reliability within the group that cannot be broken. This high level of in-group trust creates strong bonds between the members but at the same time, it creates strong division and distrust between members of different groups [50]. In an environment dominated by these hidden informal networks, people may belong to different groups at the same time with different level of commitments to each of them. This aspect generates more feelings of uncertainty and distrust among people because it is more difficult to identify who is loyal to who [45].

3.5. Role of education on the adoption of biogas technology

The adoption, design and utilisation of the appropriate biogas technology have to overcome a variety of technical, operational and socio-cultural barriers that are described in the previous sections. The good performance and dissemination of biogas plants would thus require an adequate well-trained workforce that cares for the digester every day. The lack of education and technical skills among people involved in the renewable energy sector is considered one of the main reason for poor utilisation of this type of technologies [58]. A more 'informed' society, especially end-users, policymakers and other stakeholders, including the benefits and issues of the adoption of this kind of technology, represents a crucial solution for the majority of socio-cultural and institutional limitations [58].

In SMEs, as a base of adequate work planning and record system, there is an efficient education and training system. However, the education level of workers in SSA, especially in rural areas, are very low compared to the Western average. Moreover, according to Al-Samarrai and Bennel [5], secondary school and university leavers are increasingly incapable to find an appropriate job that can transfer practical knowledge and skills. For these reasons, lack of education and lack of practical knowledge due to joblessness or inadequate training courses has to be considered with more seriousness, especially in rural areas where the educational level is the lowest [27].

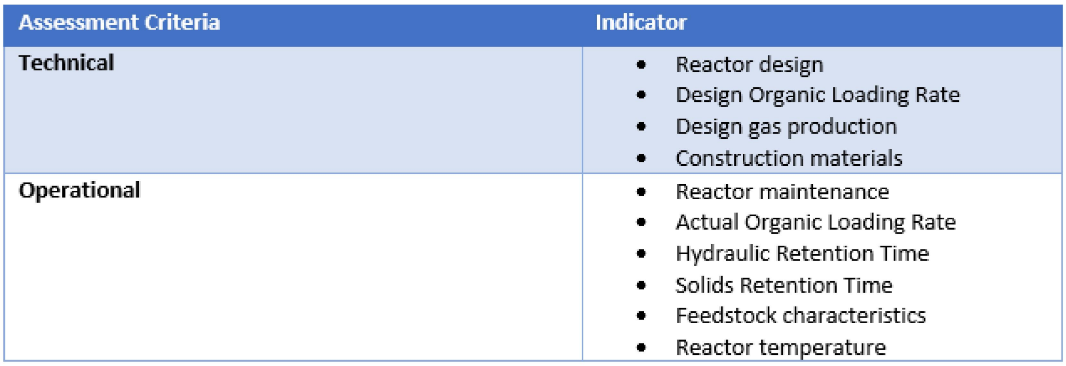
Data confirmed by UNESCO show that in Sub-Saharan Africa 33% of the total of children, adolescents and youth, are not attending school [118]. A noticeable amount of children, between ten and twelve years old, cannot keep being educated at school and begin an apprenticeship after the primary educational level. Poverty and premature work are the main reasons for the lack of education because many children are used to carrying on family work or community activity to help their families economically.

The importance of having a solid educational background through a pre-vocational knowledge training is crucial to avoid poverty and to give them a chance to develop a future vocational occupation [127]. In SSA, most of the domestic activities, especially for the agricultural sector, are considered "informal" defined by the International Labour Organisation as "all economic activities by workers and economic units that are – in law or practice – not covered or insufficiently covered by formal agreements" [127]. Informal sector represents the major practical knowledge provider for its employees since through self-training, learning from families, on-the-job apprenticeship and traditional apprenticeship, they acquire skills and insights about their profession. Ait Saudane [4] reports a statistical survey developed in Morocco in 1997 and 1999/2000 regarding the informal sector in the urban area that reveals only 4% of informal employees have attended an official vocational training course, whereas 80.3% of the people surveyed has experienced on-the-job training. Another survey carried out in Ethiopia [127] demonstrates that formal training is very uncommon among local workers since only 0.09% have attended any type of formal training, whereas 67.86% made self-training, 26.88% learnt from family and 3.54% experienced on-the-job training or informal apprenticeship.

The development of biogas project in SSA is strictly connected to the diffusion of training sessions organised for people involved in planning, constructing, operating and maintaining biogas plant [74]. In South Africa, the Three Crowns Rural School represents an incredible example of how anaerobic digestion and biogas technology can be taught starting from the children. This small rural school transformed its kitchen food waste, and agricultural and human waste into biogas for cooking and nutrient-rich fertiliser for the cultivation of vegetables in its small fields. In addition, this school provides a remarkable life-science laboratory where children daily witness the benefits coming from the utilisation of this technology and understand crucial concepts like biogas, decomposition, recycling and sustainability [74]. Francois Nel, head of environmental health and community services for a South African district, stated his positive opinion on this type of projects and their power to change the way people think:" The first thing is the education of the children and changing the mindset in terms of energy, waste, and climate change. And the ownership – the children take ownership of the environment and the importance of protecting it." [74].

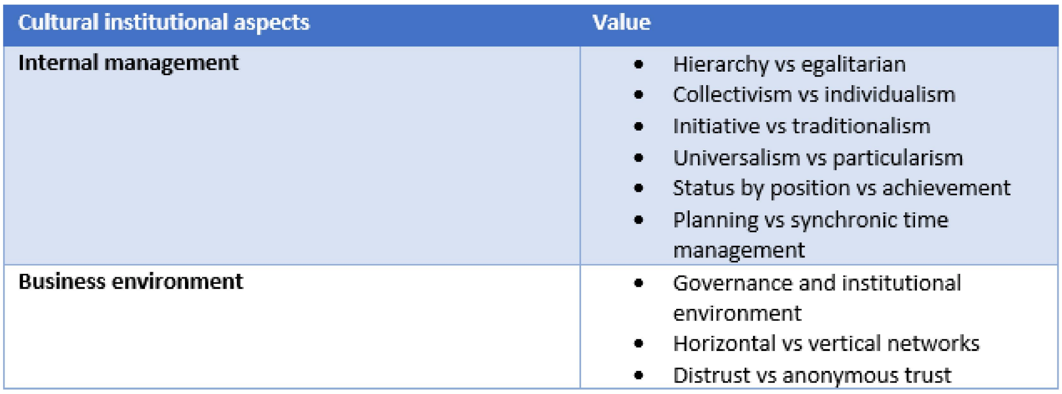
3.6. Literature results

In the previous paragraphs, the findings of the literature research concerning technology, operations, internal management and business environment were described. Using these findings of the literature research, it was possible to develop two tables forming an evaluation framework that is going to be used during the case study analysis and they are shown in Figure 3.7 and 3.8. The first table contains specific indicators related to technical and operational issues, while the second table describes cultural institutional parameters that influence the success of the biogas plants operations. It is important to mention that these tables are based on different sources of literature. The first is based on the scientific literature specifically focused on biogas technology. The second table is based on literature about entrepreneurship in a different institutional and cultural context in general and describes cultures dimensions obtained from empirical research which is generalised into overarching concepts.



Assessment Criteria	Indicator
Technical	• Reactor design • Design Organic Loading Rate • Design gas production • Construction materials
Operational	• Reactor maintenance • Actual Organic Loading Rate • Hydraulic Retention Time • Solids Retention Time • Feedstock characteristics • Reactor temperature

Figure 3.7: Technical and operational indicators for the performance characterisation of a small-scale biogas plant based on the literature research



Cultural institutional aspects	Value
Internal management	• Hierarchy vs egalitarian • Collectivism vs individualism • Initiative vs traditionalism • Universalism vs particularism • Status by position vs achievement • Planning vs synchronic time management
Business environment	• Governance and institutional environment • Horizontal vs vertical networks • Distrust vs anonymous trust

Figure 3.8: Cultural institutional values as preconditions for the performance of a small-scale biogas plant based on the literature research

It can be noticed that these tables constitute the tool for the case study analysis to answer the research sub-question 'e'. Also, the technical/operational parameters and the socio-cultural values are arranged according to the literature research to give a structured overview of the ideal description of the technical and socio-cultural aspects of a small-scale biogas plant in the SSA context. Nonetheless, these tables will be used to analyse the case studies of chapter 4 and through that, the researcher will see whether the parameters/values return in the case descriptions to validate them. Lastly, the tables based on the literature results and the case study analysis will be used to develop the recommendations for a good biogas performance and therefore to answer the research sub-question 'f'.

4

Analysis

This chapter describes and evaluates the findings gathered both during the literature research and during the fieldwork in South Africa based on the tables developed in section 3.6. The case descriptions and their analysis will be accomplished in the first paragraph through the use of the evaluation framework previously developed. This is followed by the analysis of the main issues experienced by the biogas plants described in the case studies following the parameters and the cultural values that characterise the evaluation framework. Each issue will be analysed considering the factors that could lead to the generation of the failure and the consequences generated by it in terms of the model's parameters. The last paragraph uses these findings to support, validate or broaden the evaluation assessment that has been developed in paragraph 4.3, and see whether these parameters return.

4.1. Case studies in Sub-Saharan Africa

In this section, five case studies will be described and analysed successively through the use of the evaluation framework developed in paragraph 3.6. Each case study represents a different country located in SSA (Ghana, Tanzania, Ethiopia, Kenya, South Africa), and it describes a survey conducted of several small-scale biogas plants where operational, management and socio-cultural factors are put under the spotlight. All of the case studies are gathered from the literature, except the South African case which illustrates a personal experience of three months spent in Johannesburg where I conducted several interviews to biogas experts and users, and I also visited 5 biodigesters around the area.

4.1.1. Case description 1: Ghana

This case study describes a survey conducted in Ghana by Bensah of fifty biogas plants that represented around half of the certified installations in the whole country in 2009 [8]. The majority of the plants are located in Greater Accra and Ashanti regions, and specifically in major towns and cities, where a proper infrastructure and utility network is present. Table 4.1 shows the geographical distributions of the several biodigesters visited.

Location	N. plants	Location	N. plants
Appolonia (GR)	7	Abeman/Oshiuman (GR)	1
Accra (GR)	6	Tepa (AR)	1
Okushibli (GR)	5	Ejura (AR)	1
Kumasi (AR)	4	Mankranso (AR)	1
Obuasi (AR)	4	Prampram (GR)	1
Tema (GR)	2	Oyibi (GR)	1
Koforidua (ER)	2	Tetrem (AR)	1
Tamale (NR)	2	New Tafo (ER)	1
Kotoku (GR)	1	Nkawkaw (ER)	1
Hebron (GR)	1	Akwatia (ER)	1
Miotso (GR)	1	Nsawam (ER)	1
Jisonayilli (NR)	1	Battor (VR)	1
Gambaga (NR)	1	Ankarful (CR)	1

Table 4.1: Geographical distribution of surveyed biogas plants in Ghana. Retrieved from: [8]

In terms of performance, 22 of 50 plants were fully operating, 10 were partially operating (some issues such as gasholder deterioration, gas pipelines and appliances corrosion), 14 not operating, 2 abandoned and 2 under construction. Figure 4.1 describes the operating status of the biogas plants at the time of visit (2009).

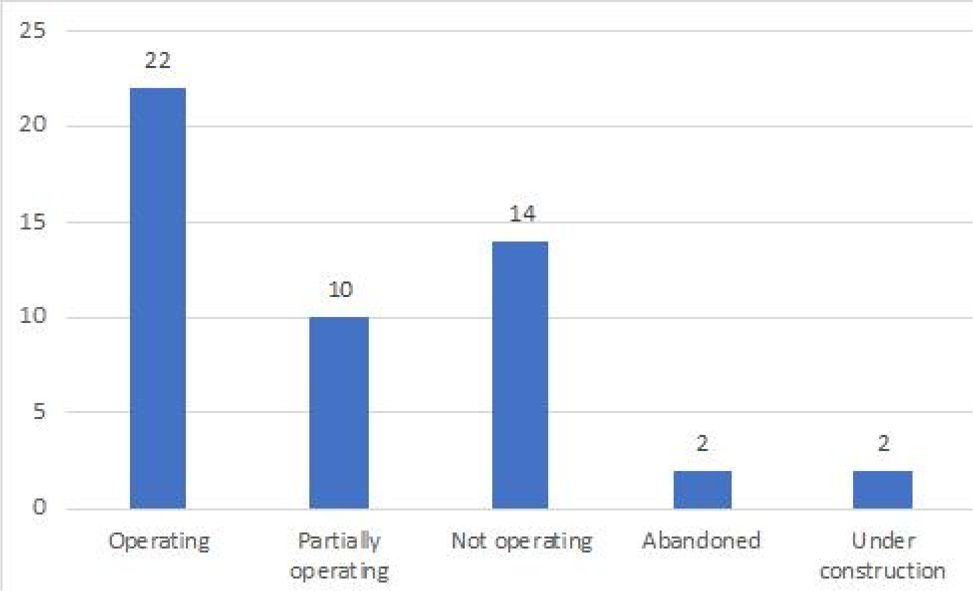


Figure 4.1: Operational conditions of biogas plants at the time of visit. Retrieved from: [8]

The biogas plant in St. Dominic Catholic hospital is the oldest operating digester with 15 years of uninterrupted functioning despite several issues experienced during its lifetime such as corrosion of gas delivery systems. From 1981 to 1990 12 plants were constructed/implemented thanks to the biogas programmes in the Greater Accra Region, in particular at Appolonia and Okushibli communities. From 1991 to 2001, 3 plants were commissioned in Appolonia, where the plant construction was enabled by the 'Appolonia Electricity' programme. Moreover, 3 additional biogas plants were installed in three hospitals at Battor, Nkawkaw, and Akwatia. In 2000, the Biogas Technology West Africa Limited (BTWAL), the leader biogas company in Ghana, was founded and a large number of biodigesters was installed by this company from 2001 to 2009. In the latter period, an additional big push for the biogas dissemination was given by Beta Construction, an important civil engineering company that realised more than 20 Puxin digesters in Ghana since 1995. Figure 4.2 shows the construction periods of the surveyed biogas plants from 1981 to 2009.

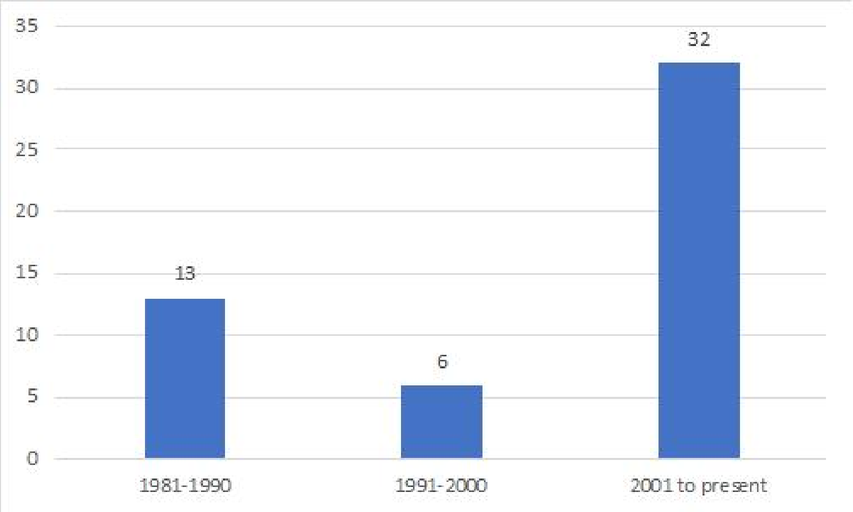


Figure 4.2: Period of construction of surveyed plants. Retrieved from: [8]

In terms of digester type, more than half of the surveyed plants were institutional, in particular in schools, hospitals and real estate areas. The rest were community and households as it can observed in figure 4.3.

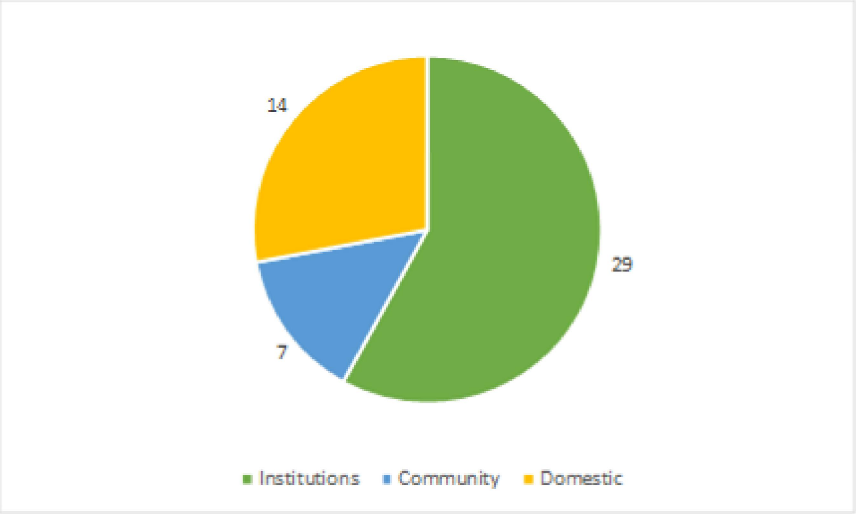


Figure 4.3: Different groups of the surveyed biogas plants. Retrieved from: [8]

Most of the domestic biodigesters broke down after 5 years of operating time due to several issues including cow dung availability and poor construction. Due to the non-availability of cow dung, communities stopped to build biodigester for cow dung as feedstock after the 'Appolonia Electrification' programme and this factor was supported by the lack of specific promotion programmes in cattle-rearing areas in Ghana.

Two types of biogas plant design are mainly used in Ghana for the construction of small-scale digesters, and they are the floating-drum and the fixed-dome. All the floating-drum digesters are of the water-jacket design, and all of their gasholders are made of mild steel, except for two of glass-fibre at Tepa slaughterhouse and Holy Family hospital in Nkawkaw, and a high-density polythene gasholder in Accra. However, more than 80% of the small-scale digesters are fixed-dome due to their lower cost. The main fixed-dome models utilised by biogas companies are the CAMARTEC model, the Chinese dome model, and lately the Puxin model. Figure 4.4 shows the different types of digesters installed in Ghana.

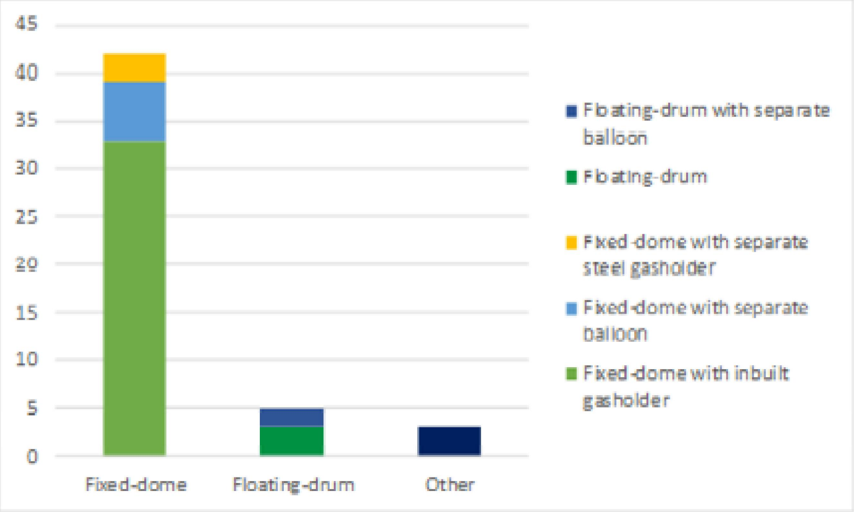


Figure 4.4: Different design of the surveyed biogas plants. Retrieved from: [8]

The size of the surveyed plants ranges from 10 to 50 m^3. The table describes the size of the digesters constructed in Ghana. Typically the 10 m^3 are installed at the households, while 50 m^3 digesters are mostly used in institutional environments. In addition, for the biodigesters that treat waste such as night soil, the retention time factor is crucial in order to let the waste be completely treated and discharged in a condition that does not constitute a health hazard to the end-user and the environment. Most of the biogas company adopted a retention time that ranges between 30 and 60 days for the design of their systems, with the adoption of post-treatment facilities including filtration tanks or concentrated solar systems for the effluent treatment. However, the retention time used in their biogas plant was considered low and inappropriate for an effectively safe effluent.

The gas utilisation of the surveyed plants was quite limited. Due to the limited amount of biogas plants that treated cow dung, both the users and the biogas companies relied more on the sanitation capacity (treatment of the waste) than on the energy capacity (use of biogas) of the plant. The diffusion of this mindset led to the construction of biodigesters without focusing on the usage of biogas, therefore enabling the gas leakage. Figure 4.5 describes the gas utilisation of the 32 operating surveyed plants.

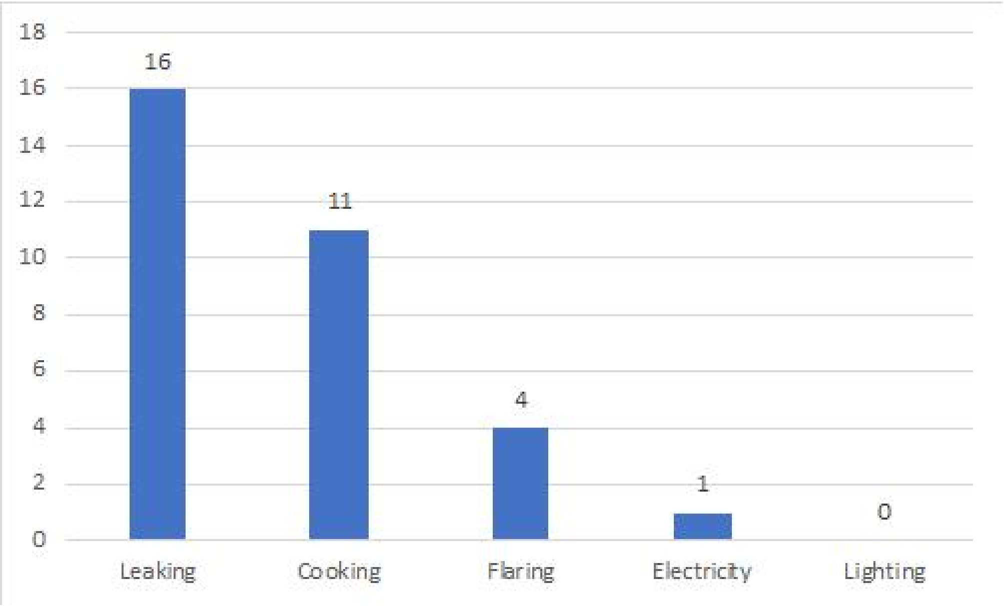


Figure 4.5: Gas utilisation of the surveyed operating biogas plants. Retrieved from: [8]

Of the 32 operating (both fully and partially) plants, 12 experienced gas leakage issues. At the two hospitals of Holy Family and St. Dominic, the balloon gasholders were completely deteriorated causing gas leakage into the air and the misuse of biogas appliances. Moreover, the majority of the owner of biogas plants that treat excreta didn't use the biogas neither flare it. The use of effluent of the biogas plants as organic fertiliser was very rare in Ghana. The digested slurry was not considered as an asset for the owners but most of them discharged the effluents into some bush close to the plant or the public drain. The major issue concerning the productive use of the effluent was the safety of the slurry produced by the sanitary biodigesters. This aspect was mainly enabled by the cultural attitude towards the use of effluent that comes from human excreta as fertiliser. Figure 4.6 highlights the effluent utilisation by the owners of biogas plants.

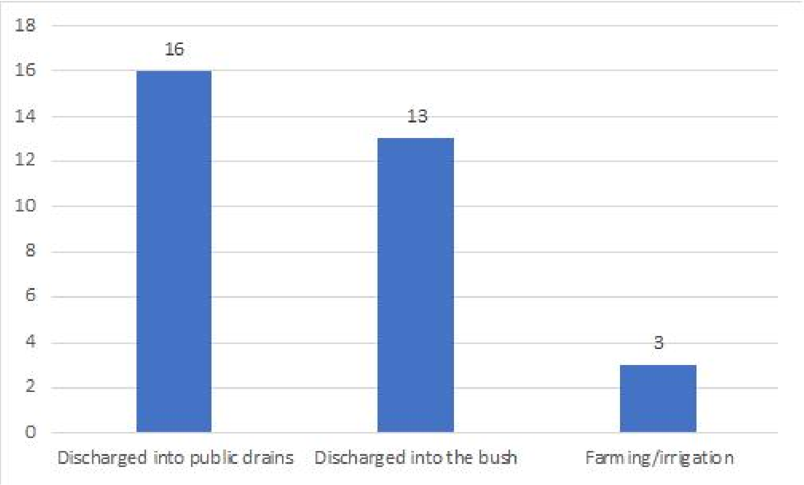


Figure 4.6: Effluent utilisation by the owners of the surveyed operating biogas plants. Retrieved from: [8]

In terms of maintenance, the survey has demonstrated that most of the plants stopped working due to the lack of good operational and maintenance activities, such as constant daily feeding, cleaning the biogas appliances, checking gas leakages and fixing balloon gasholders. The main reason for this poor maintenance was represented by the lack of skilled caretakers of the biogas plants in Ghana. The lack of knowledge among the biogas users is caused by a low education level of the workers and by insufficient training from the biogas companies. Only 3 biogas plants (located in Anglogold Ashanti Limited) out of 50 were daily maintained by trained technicians that ensured a constant operation of the plants. The survey revealed that most of the biogas plants used for treating human excreta broke down due to the lack of basic knowledge of the components and functions of the technology by the caretakers. In addition, according to the biogas users, the service companies didn't provide a sufficient education on the technical aspect of a biodigester to the local users that struggled to communicate with them. For this reason, most of the owners, as soon as they encountered an issue of the biodigesters, were unwilling to repair it since they did not want to spend more money and time. Service providers attributed the lack of follow-up services to the absence of financial funds to carry out the biogas assistance.

Most of the biogas plants presented at least one or two caretakers of the digesters that are managed by the owner of the plant, especially for domestic biodigesters since most of the owners had different commitments and they did not want to spend too much time on this technology. The other biogas plants were maintained and managed by the caretaker in charge of feeding and controlling the plant by the community or the institutional environment. According to the maintenance manager of the fixed dome digester in the Fiesta Royale Hotel in Accra, his employees needed a lot of instructions for the good operation of the plant because they forgot easily and needed to be reminded every one or two weeks, especially if they are new. Even though there was quite a power distance between the manager and the workers and he used to push them to work hard, the biogas plant was operating since 2007 and it was treating night soil producing biogas that is then flared into the air. Another example of internal management is given by the household biogas plant at Okushibli of 50 m^3 constructed in 1990 and fed with cow dung until it stopped working. The owner of the plant managed two workers that were paid to manage the digester. Through the survey, it is clear that the decisions were only taken by the owner and his employees always had to consult him because they didn't have the technical knowledge to build their own ideas and because the owner didn't want to give him any responsibilities for the maintenance of the technology. Occasionally, one member of his family used to control the workers if they were working correctly when the owner was outside for work. In the plant rules are very limited, as the only rule to be present was the punctuality at work. In addition, the owner used to record the activities in his notebook about the feeding rate and the dung collection. However, as soon as the biodigester stopped running for a breakdown of the gas pipes and the gas stove, the users were not able to fix the problem, and at the same time, they failed to reach the construction company for a maintenance service. For this reason, they decided to stop using the biodigester since they were not willing to spend more money and they could use the wood fuel of the village.

In terms of governance and institutional environment, more than ten biogas companies were involved in the promotion and construction of biogas technology in Ghana even without the support of the government. However, a lack of communication and follow-up service by the same service providers is evident and this factor affected negatively the operation and maintenance of the biodigesters where the users were not able to do it by themselves due to a lack of technical knowledge. In addition, in Ghana, a national biogas programme is still absent. Therefore, the high cost of the installation of a small-scale digester for local farmer due to the lack of subsidies and financial support from the government and the lack of cooperation with the service providers after the construction of the plant represent one of the major factor of discouragement to install new biodigesters or to spend more money to maintain the current malfunctioning biodigester.

4.1.2. Case analysis 1: Ghana

The case study of Ghana is characterised by the 54% of the total surveyed biogas plants in partially or not operating condition (excluding the 2 plants under construction). These biodigesters experienced several techno-operational problems during their operating lifespans such as gas leakage, blockage of the inlet pipe, no-availability of water, deterioration of the balloon gasholder, no-availability of cow dung as feedstock, scum formation, and biogas appliances corrosion.

Gas leakage is the most occurring issue in this case, and it is considered not only a biogas production inhibitor but also a health hazard for a household in case of inhalation of the gas and a potential cause of fire explosion since, under specific concentration of biogas, the gas can be explosive in contact with air. In addition, in the case of biogas leakage in the air, the environment is seriously damaged by the release of around 60% of methane which is one of the most dangerous greenhouse gas. This issue is mainly generated by two aspects, a poor quality construction material and the no-use of the biogas produced. The application of poor materials during the construction of the biodigester is caused mainly by a prohibitive initial investment cost that neither the local user nor the biogas company can afford without any financial support from the government or international organisations, and/or by the non-availability of local materials that leads to promote material imports. However, more than 90% of the total gas leakage issues occurred in the case study is due to the no-application of the biogas produced that is released freely into the atmosphere by the caretakers. This is caused by several factors, such as financial, since farmers or institutions cannot afford the purchase of biogas appliances, technical, since users prefer to avoid technical problems for the use of biogas adopting traditional fuels, and knowledge, due to the lack of on-site training on the construction, operation, maintenance, and servicing of biogas generating systems.

Another issue occurring quite often in the case study is the blockage of the inlet pipe. More than 20% of digesters experienced this problem which caused basically by the introduction of materials with higher dimensions than the diameter of the inlet pipe. Two biodigesters stopped running due to the introduction of large size kitchen waste into the mixing tank, while the other three bio latrines broke down due to the introduction of polythene and pieces of cloth materials inside the digester. In both cases, a filtering system of the feedstock before entering into the plant is necessary in order to avoid the introduction of undesirable feedstock.

The no-availability of water is a crucial factor for the performance of the biogas plant, especially in Sub-Saharan Africa where most of the countries (including Ghana) have limited and seasonal water resources. In addition, where the water source is way far from the biogas plant, the water collection can be problematic and can be connected with health and social issues. This is the case of the Gambaga community where women were in charge of collecting water for the community. They were reluctant to spend more time and energy to collect the extra water requested for the biogas production because more water they have to collect, the less time they can spend on other activities. Additional water collection techniques are necessary in order to limit the effort spent and to provide a constant water feed for the biodigester. Recycling domestic water is the easiest and cheapest way to increase the availability of water, such as through the use of urine for wet fermentation in the digester [102]. Another technique can be rainwater harvesting and aquaculture.

The deterioration of the plastic balloon gasholder can be considered one of the causes of gas leakage and it is experienced by two floating-drum digesters in Ghana case study. Both are constructed in 1994, which is 15 years before the realisation of the survey. Aged biogas plant and direct exposition to solar irradiance are the main factors for the deterioration of plastic gasholders and to avoid this kind of damage a roof that protects the bag from direct solar radiation is necessary [124]. Moreover, a fence can be useful to protect against damage by animals [124].

The biodigesters affected by scum formation are characterised by the treatment of a mixture of different biomass, such as nightsoil with kitchen waste for the case of the Kinder Paradise Children's Orphanage in Prampram, and slaughterhouse with dung for the case of the Department of Animal Science Slaughterhouse. Improper preparation of the influent feedstock is the main reason due to the lack of a milling system or a filtering system that could remove the inert materials such as rock and sand [12]. Moreover, an optimal mixing system can hinder the formation of scum thanks to faster degradation of the proteins inside the digester that constitute the scum [111].

Finally, the corrosion of the biogas appliances is another frequent operational issues that can be easily prevented by regular cleaning of the gas jets in case of biogas stoves or of the gas valve in case of biogas lamp. The corrosion aspect is caused by the high water vapour content of the biogas that can react with the hydrogen sulphide generating ionic hydrogen and/or sulphuric acid, which is corrosive to metals. Installing a water trap and burying underground the outlet pipe in order to increase the water condensation is necessary wherever this issue occurs frequently [72].

The typical structure of a biogas plant is hierarchical, with an owner or manager and one or two workers that need to be "instructed" about their tasks. The decisions are taken from the top to the employees and they are not allowed to take the initiative without consulting first their superior. At the Okushibli case, the owner didn't want to give too many responsibilities to his workers, since he was also the only one who was controlling the performance of the biodigester.

A professional attitude among the workers was very limited. They needed to receive constantly directions and tasks of the biogas activities. However, there was cooperation between workers even if they belong to different gender or age groups. This can be explained by a communitarianism value that characterises the whole African society. A fatalistic attitude seems to be present in several cases. Due to the lack of a standardised manual for the biogas production, the manager and his workers couldn't follow a proper manual. In

addition, they didn't have any tool or device to monitor the performance of the biodigester, except for some gas meters that most of them were corroded at the time of the visit. Rules at the plant were very limited without any consequences in case of misconduct.
Time management was synchronic in most of the cases. Usually, workers didn't have a strict work schedule and they didn't record their activities. This is evident from the inconstant feeding system of some cases and from the lack of a record system from the manager. The main reason is the lack of knowledge of the users of the biogas plants, which were not trained sufficiently by the biogas companies (only 3 plants out of 50 were monitored by trained engineers)

Despite the lack of support from the national government, Ghana case study showed several achievements reached by biogas companies. The country has to give credits to the biogas companies involved in the dissemination of a remarkable amount of biodigesters, that promoted the technology on the business ground, helped to improve the sanitation condition in urban and rural areas, and created job opportunities through the construction of the reactors. However, a coordinated national programme that will promote and diffuse the technology in both rural households and institutions is necessary. Moreover, some cases demonstrated the inability of some biogas service providers to communicate with the users in terms of maintenance training or simple follow-up service after the installation. This aspect promotes indirectly the distrust on people or companies that comes from different vertical networks since potential biogas users are more sceptical about the installation of a new biogas plant due to the lack of follow-up service by biogas companies.

4.1.3. Case description 2: Tanzania

This case study describes a survey conducted in Tanzania by Lohri of 12 small-scale biogas plants as a thesis project for the Zurich University of Applied Sciences [71]. The visited plants are located in Dar es Salaam, the former capital of Tanzania and the biggest economic centre of the country. All of the biodigesters are at the household level with a standard digester volume of 1 m^3 (except for two digesters of 2 m^3), and the type used is the ARTI Compact biogas system (CBS). The system is based on two cut-down high-density polyethene (HDPE) water tanks, with standard inlet and outlet pipes. The bigger tank is used as digester while the smaller is inverted and directed into the digester in order to act as a floating gas holder. This particular system is designed for treating daily 1-2 kg (dry weight) of kitchen waste. Figure 4.7 describes the scheme of the ARTI CBS.

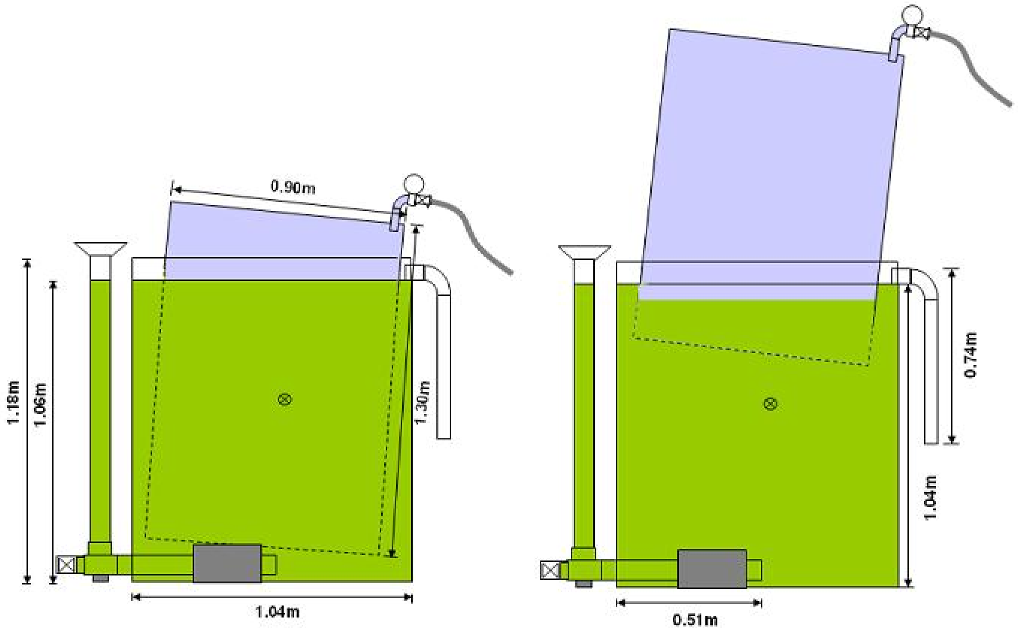


Figure 4.7: ARTI Compact biogas system adopted in the surveyed biogas plants. Retrieved from: [71]

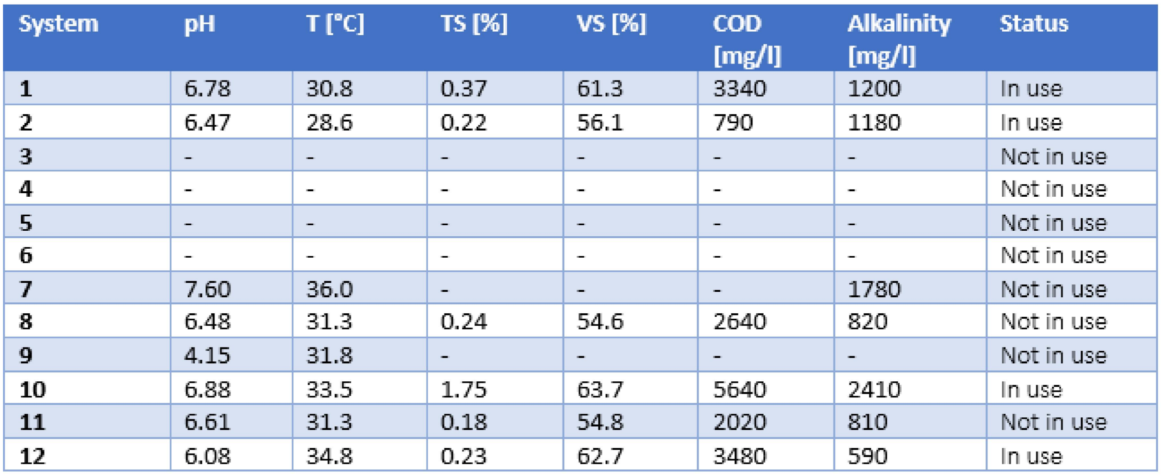
In terms of performance, 4 of 12 plants were fully operating, while the other 8 were not used for several reasons. However, 3 out of 4 operating plants produced an amount of biogas that is below the optimal range (0.144-0.275 Nm^3 gas/m^3 digester volume per day). Table 4.2 describes the operating status of the biogas plants at the time of visit (2008) with some remarks per each plant.

System	Installation year	**Size digester** [m^3]	**Status**	**Remarks**
1	2007	1	In use	Many invertebrate larvas inside the digester
2	2007	1	In use	Use of water heater to reach the optimal T; gas leakage from the outlet pipe
3	2007	1	Not in use	Inlet feedstock run out
4	2007	1	Not in use	Undefined cause of breakdown
5	2007	1	Not in use	Blockage inlet pipe; gas leakage from the gasholder
6	2007	1	Not in use	Undefined cause of breakdown
7	2008	1	Not in use	Blockage inlet pipe; gas leakage from gasholder; inlet feedstock not enough
8	2008	1	Not in use	Gas tap broken
9	2008	2	Not in use	Overfed
10	2008	2	In use	Inlet pipe slightly blocked; gas leakage
11	2008	1	Not in use	Overfed
12	2008	1	In use	Blockage inlet pipe

Table 4.2: Description of the surveyed small-scale biogas plants, including the year of installation, the size, the status, and some remarks about operating issues. Retrieved from: [71]

All the biogas plants were installed between 2007 and 2008, so they are very recent compared to year of visit (2009). The systems were installed by the Appropriate Rural Technology Institute Tanzania (ARTI-TZ), an non-governmental and non-profit organisation founded in 2007. With the collaboration of Joint Environmental Techniques (JET), as company specialised in constructing, manufacturing and selling biodigesters in Tanzania, ARTI-TZ installed since 2006 until 2008 31 ARTI Compact biogas systems in Tanzania and Uganda.

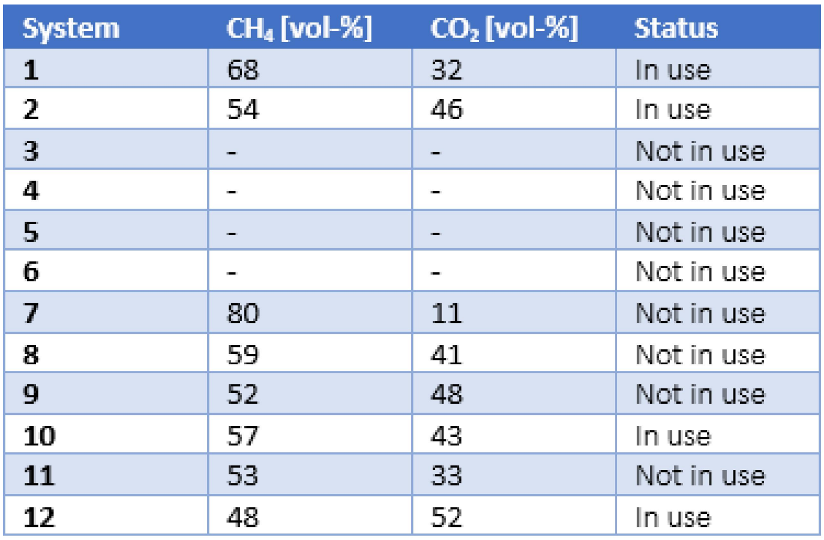
Figures 4.8 and 4.9 present a technical overview of the surveyed biodigesters, including the effluent characteristics and the biogas composition.



System	pH	T [°C]	TS [%]	VS [%]	COD [mg/l]	Alkalinity [mg/l]	Status
1	6.78	30.8	0.37	61.3	3340	1200	In use
2	6.47	28.6	0.22	56.1	790	1180	In use
3	-	-	-	-	-	-	Not in use
4	-	-	-	-	-	-	Not in use
5	-	-	-	-	-	-	Not in use
6	-	-	-	-	-	-	Not in use
7	7.60	36.0	-	-	-	1780	Not in use
8	6.48	31.3	0.24	54.6	2640	820	Not in use
9	4.15	31.8	-	-	-	-	Not in use
10	6.88	33.5	1.75	63.7	5640	2410	In use
11	6.61	31.3	0.18	54.8	2020	810	Not in use
12	6.08	34.8	0.23	62.7	3480	590	In use

Figure 4.8: Overview technical parameters of surveyed biogas plants, including effluent characteristics (pH, T, TS, VS, COS, and alkalinity). Retrieved from: [71]

In general, effluent characteristics and biogas composition of the inspected systems corresponds with the operational parameter ranges that characterise this type of design. The pH value should generally stay between 6.5 and 7 for an optimal performance, since below 6.0 the methanogenic activity is limited. For the temperature, an average value of 32.3 °C is shown, which is slightly below the optimal value but it is perfectly comprised into the mesophilic range (30 - 45 °C). The low TS content of the effluent is due to the high liquid content of it, while a relatively low VS percentage is due to the presence of inorganic components of the effluent. An optimal range of the alkalinity for this type of digester is between 800 and 1200 mg/l.



System	CH_4 [vol-%]	CO_2 [vol-%]	Status
1	68	32	In use
2	54	46	In use
3	-	-	Not in use
4	-	-	Not in use
5	-	-	Not in use
6	-	-	Not in use
7	80	11	Not in use
8	59	41	Not in use
9	52	48	Not in use
10	57	43	In use
11	53	33	Not in use
12	48	52	In use

Figure 4.9: Overview technical parameters of surveyed biogas plants, including biogas composition (CH_4 and CO_2). Retrieved from: [71]

In terms of biogas composition, all of the operating biodigesters had good values, except for the digester number 7 that had a too high-methane content, and the number 12 with its low-methane concentration. Moreover, the biogas was utilised only for cooking as the company ARTI-TZ provided the users with a biogas stove that should burn 0.2 m^3 of biogas for a period of 45 min. A household on average spends 2.5h per day for cooking (average of 5 members). An issue experienced by 3 operating biodigesters is that they didn't have enough kitchen waste to produce a sufficient amount of biogas for cooking every day, therefore they needed to buy charcoal in order to compensate the missing fuel. The owner of one abandoned plant stopped to feed the biodigester because he preferred to sell the kitchen waste to the neighbouring pig farmers. Moreover, all the biodigesters had gas losses through the rim between the digester and the gasholder of about 22%.
The effluent that came from the digestion process did receive any accurate analysis because the quality of the slurry as organic fertiliser was considered suitable for a limited amount of plant where it is applied. The author had also considered the comparison with the Quality Standards of Compost of limited validity. For this reason, the biogas users used to throw the effluent in the nearby bush in order to get rid of the slurry and don't generate blockage of the outlet pipe.
The interviewer observed that the main causes for the malfunctioning of the biodigesters were three: the lack of proper instructions by the biogas company ARTI-TZ, the poor maintenance of the biodigester by the operator, and the lack of follow-up service by ARTI-TZ. These issues then led to the operational problems that are described in table 4.2, which are the blockage of the inlet pipe, gas leakage, overfeeding, and the gas tab is broken. Moreover, all the biodigesters had problems with the condense water that blocked the gas hose and two surveyed plants not in use had the burner too far from the digester. In general, the interviewed operators didn't answer very accurately to the operational questions because they did not have the technical knowledge and they were not maintaining the digesters constantly.

In terms of internal management, the biogas plants presented at least one caretaker that maintained the digester. The people interviewed were the owners. It was evident a hierarchical management style of the workers due to an unequal relationship between the superior and the subordinate. The owners gave weekly instructions on the activities that have to be done for the running of the biogas plant, especially for the feeding step that it was not constant. However, the communication between the workers and the supervisor was present and the latter was very open listening to the workers' opinions because most of them said that the "group is like a family where all the members has to listen and taken into consideration", even if at the end the owner is always the only one who takes the decision. In one case, the employees were free to express their idea, but the problem was that, as soon as they were asked to provide examples where the whole biogas maintenance could be improved, they were not able to do it. In most of the biodigesters, poor maintenance was evident due to a superficial attitude of maintaining the technology by the workers that are originated by a deep indifference of the owner. The author of the research expressed his disappointment when he saw the inaccurate answers received regarding the operating conditions of the digesters, and in some cases, the operators could not give a motivation for the complete breakdown of the plant.
The lateness of the employees seemed to be quite usual in the biogas plants. However,

they could be penalised if they didn't have a valid reason or if they were late several times. One owner used to take quite authoritarian measures to improve the punctuality: he would subtract the monetary value of the time lost from the salary if the delay would be frequent. In addition, a planning scheme or a record system were missing in all of the biogas plants and this was often leading to not feeding the digester every day. Some owners explained the lack of a physical scheme with the fact that they did the planning from the top of their head.

According to Rupf et al. [105], the Tanzanian government is supporting most of the biogas projects in the country. His main role is to support financially (funding or subsidies) the biogas companies that provide reliable energy services to end-users. The Centre for Agricultural Mechanization and Rural Technology (CAMARTEC), a government research organisation, is playing a key role in the dissemination of biogas technology in the country, especially in rural areas. In addition, the organisation provides training for digester constructors, and practical workshop for biogas users, especially women, on the management and operation of the technology.

However, the case study showed a lack of proper instruction by the biogas company ARTI-TZ which led to a low knowledge about the operating and the maintenance of the biogas plant. Moreover, a lack of follow-up service by them affected negatively the relationship between the users and the service company due to a lack of communication and also it affected the maintenance of the biodigester. Some owners expressed their ignorance about the condition of the digesters because they did not receive any instructions or manual that could explain how to monitor the performance of the plant.

4.1.4. Case analysis 2: Tanzania

The optimal gas production rate of an ARTI Compact system, fed with kitchen waste, is measured between 0.144-0.275 Nm^3 gas/m^3 digester volume per day, with a methane concentration that ranges between 57 and 66%. The case study of Dar es Salaam shows a biogas production slightly below the optimal value for the operating plants, with just 1 plant that produced around 0.2 Nm^3 gas/m^3 digester volume per day. The low-methane content of the biogas produced by the plant number 12 can be explained by the fact that it was recently installed (1 month before the visit), and high production of CO_2 during the hydrolysis step typically characterised the start-up period of a biogas plant. The too high-methane content of the biogas plant number 7 instead is a direct consequence of the breakdown of the digester due to the congestion of the feedstock. Moreover, a high amount of broken digesters characterised this case study with around 67% of not operating biogas plants. The high number of not operating plants and low biogas production for the operating ones were caused by several operating issues that included gas leakage, blockage of the inlet pipe, overfeeding, and no-availability of sufficient feedstock.

According to Lohri [71], the gas leakage was mainly occurring through the rim between the gasholder and the digester with around 22% of the total biogas produced wasted into the atmosphere. In addition, water condenses occurred during the biogas production, leading to frequent blocking of the gas pipe. It is evident that further improvements of the digester design are necessary, despite the cheap and durable material used for the construction (high-density polyethene). The proportion between the gasholder and digester sizes is fundamental in order to reduce the loss of biogas. The same author observed a reduction of biogas loss to 14% using a different type of tank produced by AFRITANK. Moreover, the use of Araldite, a special glue used to "weld" broken parts of the digester, to reattach broken parts, the use of solid tape is highly recommended. In this way, a total replacement of the whole gasholder in case of cracks is not necessary.

The blockage of the inlet pipe seemed to be the most frequent issue in this case study. The lack of a filtering system, that could separate big particle or inert materials like plastic from the rest, is a factor that influences this issue. Another reason for the blockage of the inlet pipe is the lack of an appropriate cutting and diluting system for the feedstock. In addition, the author suggested a replacement of the T-connector at the lower extremity of the inlet pipe with a swift-elbow one, that can enhance the flow of the feedstock inside the digester, and the installation of a 2"-ball valve to the connector in order to improve the removal of blocking material.

The overfeeding and the no-availability of feedstock are both categorised in the 'no-constant feeding' issue. The biodigester number 9 is the perfect example of digester affected by high acidity ($pH<5$) due to overfeeding. The exact opposite happens to the biodigester number 7 that was affected by not enough feedstock to use per day, and this affects the pH that increases over the limit ($pH>7.5$) and the biogas production that drops immediately. In case of breakdown, the system has to be emptied totally and filled up again with a gradual increase in the amount of feedstock and water until the digestion process find again the stability.

The hierarchical management style is evident in this case study where the owner or the manager of the biogas plant didn't have an egalitarian relationship with the workers. The employees received constant and frequent instructions for the maintenance of the biodigesters and also they had to accept the decision taken from their superior. Paternalism was present in these groups, demonstrated also by the interviewed that compared the group as a family which can be translated in mutual respects and trust between the owner and the workers. The description of the case study didn't provide any information about possible favouritism given to specific workers wherever a particular relationship with the owner was present. However, as the case study described the decisions were taken only by the superior, even if he was listening to the ideas of the workers, and a lack of initiatives from the latter is evident. In addition, the workers seemed to lack a professional attitude of maintaining independently the plant and taking responsibilities of it, since frequent instructions had to be given to maintain a proper motivation. In his report, Lohri found out that in some cases the owner discovered by himself that a decrease of biogas production was happening or that the biodigester was not fed in the morning [71].

A fatalistic attitude towards the time management is visible from the owner by giving margin to his workers to arrive late at work if they have a valid reason. This is directly connected with the performance of the biogas plant that if it doesn't respect precise daily planning, it will encounter inevitably a decrease of biogas production. For this reason, proper planning, even just a blackboard with written the tasks of the day, is necessary in order to keep the workers focused on what they need to do every day and to simplify the record of the activities achieved the same day. Synchronic time management is also shown by the owners that were limited to daily tasks without having a clear idea on the long-term goal for the plant.

Aspects concerning the business environment of this case study are very modest. It is possible to observe that there is no specific political support, in terms of financial subsidies or loans, but also specific barriers by the government for biogas dissemination are not evident. Lohri explicitly defined two big issues that caused the malfunctioning of the biodigesters: the lack of proper preparation by the biogas companies and the lack of follow-up service by them [71]. The majority of operational failures that occurred in the biogas plants were caused by poor maintenance from the workers, which was caused by a lack of technical and practical knowledge. For this reason, the biogas companies, with their biogas specialists, play a key role in the dissemination and the success of biogas projects. They should not only provide a follow-up service, especially during the start-up period of the plant, but also practical workshop and seminars to teach local communities and farmers about the benefits and the issues that the biogas technology can bring, and about appropriate operational management of the plant. The creation of a practical manual with the list of instruction can be very important in case of questions about the management and when small issues occur. The lack of communication with the biogas company can e a manifestation of vertical networks where is hard for members of different groups to build relationships of anonymous trust outside the group.

4.1.5. Case description 3: Ethiopia

This case study, derived by the research of Eshete et al., describes a survey conducted in Ethiopia of 57 domestic small-scale biogas plants [34]. The visited plants are located in the regions of Oromia, Amhara, Tigray and the Southern Nations, Nationalities and Peoples Regional States (SNNPRS). The 57 biodigesters visited can be divided into two main types: fixed dome and floating drum design. Of the 57 plants, 25 were fixed dome and they were constructed from three different programmes developed by a different organisation, including the World Vision AATPI programme (in Tigray and Oromia areas), the GTZ/Lupo programme (with the Christopher Kellner's effort) and the Mekane Jesus programme. The rest were floating drum and they were realised through governmental programmes in the period 1993-2006.

In terms of performance, 35 of 57 plants (around 60%) were not operating at the time of the visit, with a share of 8 fixed dome digesters (32%) and 27 floating drum digesters (84%). It should be noticed that many of the floating drum digesters were quite old since some of them were constructed 14 years before the year of the visit (2006). The youngest installations were the fixed dome biodigesters installed under the AATPI programme of World Vision with just 1 year from the installation date. Figure 4.10 describes the operating status of the biogas plants at the time of the visit (2006).

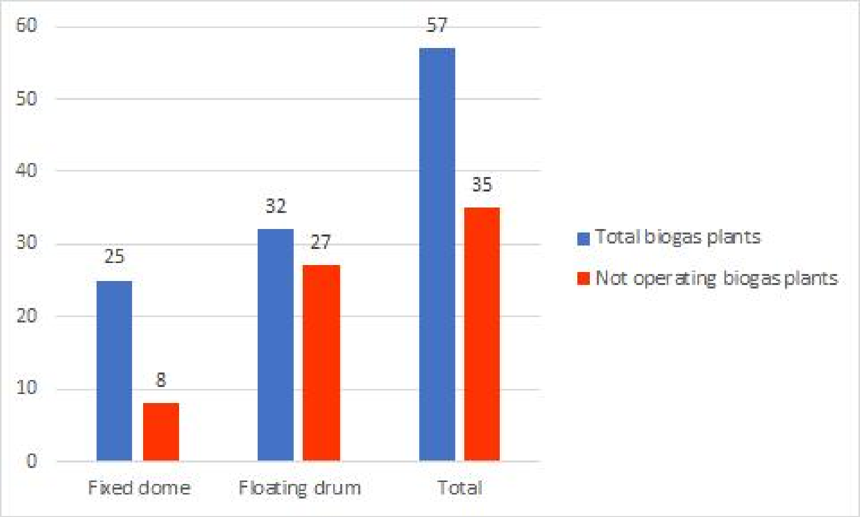


Figure 4.10: Operational conditions of biogas plants at the time of visit. Retrieved from: [34]

The gas utilisation of the surveyed operating plants is used mainly for cooking and few of them also for lighting. Most of the biogas users had one single stove, while few of them had also a specific larger one for baking the local bread. Biogas stoves were mainly constructed in Addis Abeba, and part of them was imported from India. Many stoves presented a limited performance due to corrosion of the air intake and low gas pressure, especially in the floating drum digesters. Biogas lamps in Ethiopia are very appreciated by local farmers due to a general lack of electricity that affects the whole country. However, it was observed that the interest of local people was vanishing as soon as the biogas lamp was stopped functioning. In addition, all of the biogas lamps visited were in terrible operating condition, with the majority not working. A limited amount of biogas available per household was observed due to a limited amount of dung available for the biogas digestion and to the limited efficiency of the biogas appliances. Average use of 3 hours of a normal biogas stove (250 litres biogas/hour) and 3 hours of biogas lamp (almost 120 litre biogas/hour) was considered the maximum amount of biogas available per day with the average dimension of biogas plant (around 5 m^3). Figure 4.11 describes the gas utilisation of the surveyed biogas plants.

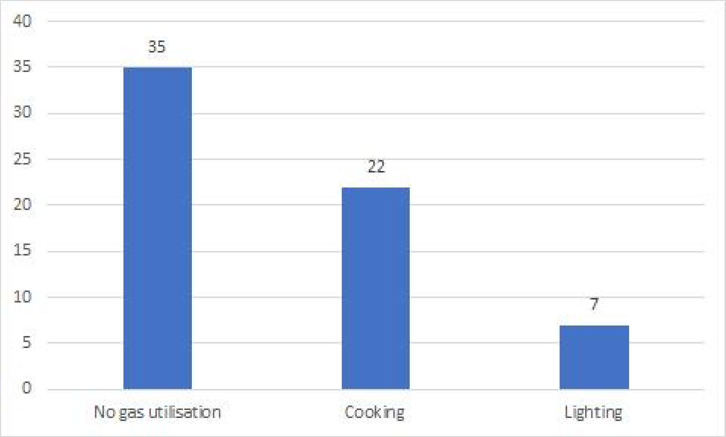


Figure 4.11: Gas utilisation of the surveyed biogas plants. Retrieved from: [34]

In terms of bio-slurry utilisation, many farmers adopted the slurry generated by the anaerobic digestion (direct of diluted, dried and composted) on their gardens to cultivate vegetables with reported increased production yield and reduced weeding. An important issue that affected this area is water availability. In 1998, a severe drought affected drastically on the cattle holding of many farmers (they had to sell their entire herd) and also caused a crucial drying up of water storages. This had caused several issues for the maintenance of the biogas plants, in terms of drying up of the substrate inside the digester and no availability of manure for the underfeeding of the cattle. In addition, in some places, the distance between the digester and the water source was too large that the farmers argued to spend more energy on the water collection that the one produced by the biogas production. As a result, many biogas plants were abandoned for several reasons, which include the dung shortage, a migration of the families and a loss of interest of the owners in operating the plants.

Most of the not operating plants had several minor issues that could be fixed with less than half a day of work of a skilled expert and small investment, according to the author, such as water condensation in the pipes, unprotected piping damaged by cattle, broken stoves and biogas lamps, and gas leakage. In some cases, major problems occurred like broken biodigesters and the blockage of the inlet pipe. However, the total absence of technical follow-up service by the biogas service providers and the lack of knowledge of the users, that seemed desperate for technical advice and operational maintenance, increased the effect of these technical and operational issues because of poor maintenance of the plant.

In terms of internal management, the biogas plants presented at least one caretaker that maintained the digester. The people interviewed were the owners of the biodigesters. The author dwelt on the role of women in these areas. A hierarchical and dominant family structure characterised the relationship between the several members of the family, with power structures divided per sex, age and relatedness. Decisions regarding education, business, farm work schedules of the household members, and the employment of local workers are taken by the head of the household. This is also reflected in the power distance between the owner of the biodigester and his workers, where the lack of communication and a paternalistic management style influence the professional attitude of the latter. It is important to notice that, the owners, when asked to define their internal management style, expressed that they need to control the performance of their workers every day because, even if they trust their attitude and motivation, the employees don't have enough knowledge to take initiative and maintain the biodigesters independently. In some cases, poor maintenance was evident due to a superficial attitude of maintaining the technology by the workers that are originated by a deep indifference of the owner. The author of the research argued the presence of inaccurate answers received regarding the operating conditions of the digesters, and in some cases, the operators could not give a motivation for the complete breakdown of the plant.

In addition, a planning scheme or a record system were missing in all of the biogas plants and this was often leading to not feeding the digester every day. The owner used to plan the schedule of the several activities in the plant in their head, without writing them up. As a result, the workers argued about a no clear definition of the several tasks in the biogas plants. Some owners explained the lack of a physical scheme with the fact that they did the planning from the top of their head.

The author described also the interviews conducted at regional Bureaus of Energy and Bureaus of Agriculture. The respondents expressed the fact that involved officials are very aware of the energy crisis and the socio-economic interactions in this topic. However, despite the awareness of the government, at the higher political level, the issue doesn't receive enough attention and priority. As a result, there is an inadequate funding scheme for the training programmes and the biogas projects. The executive bureaus expressed a bit of frustration for the limited economic resources received from the government.

In addition, the case study showed a lack of proper instruction by the biogas companies involved in the construction of the biogas plants, which led to a low knowledge about the operating and the maintenance of the technology from the biogas users. Moreover, a lack of follow-up service by them affected negatively the relationship between the users and the service company due to a lack of communication and also it affected the maintenance of the biodigester. Some owners expressed their ignorance about the condition of the digesters because they did not receive any instructions or manual that could explain how to monitor the performance of the plant.

4.1.6. Case analysis 3: Ethiopia

The case study of Ethiopia is characterised by 60% of the total surveyed biogas plants in not operating condition. These biodigesters experienced several operational problems during their operating lifespans such as water shortage, dung shortage, loss of interest, and technical issues such as water condense, blockage of the inlet pipes, and biogas appliances corrosion.

Water shortage is a very serious issue, especially in the Dessie and Amhara regions, where a high amount of floating drum digesters are not functioning. The reasons expressed in the description showed that not only natural disaster influenced this problem (severe drought in 1998), but also a lack of alternative techniques of water collection that forced the workers to do long distance to the water source. As a result, the users stop operating the plant due to a high energy and time demand, but also due to a lack of interest in the technology itself. This is also confirmed by the experiences of some cases that showed a profound interest in operating the biogas plant and to take initiatives in order to find innovative solutions for the water collection. Additional water collection techniques are necessary in order to limit the effort spent and to provide a constant water feed for the biodigester. Recycling domestic water is the easiest and cheapest way to increase the availability of water, such as through the use of urine for wet fermentation in the digester [102]. Other techniques can be rainwater harvesting and aquaculture.

Another aspect connected with the loss of interest from the biogas users is also a not appropriate plant design installed by the biogas companies, specifically in terms of size. Comparing the amount of available dung of the plant visited by the author, the plant size was too large. On average, the dimensions of the domestic biogas plants of the survey were around 8 m^3 of volume, but also sizes of 12 to 20 m^3 were noticed. However, most of the households had only 3 to 8 cattle, with an average dung daily production of 36 kg/day (considering 6 heads of cattle and a 6 kg of dung/day per head). Assuming a hydraulic retention time of 60 days and a water addition of 1 litre per litre of feedstock, a proper digester volume should be of 4 m^3. The dung shortage is a serious problem for several areas since droughts and not

correct cattle holding style limited the dung available for the digestion process and so the biogas production.
Another issue occurring quite often in the case study is the blockage of the inlet pipe. More than 70% of the not operating digesters experienced this problem which is caused basically by the introduction of materials with higher dimensions than the diameter of the inlet pipe, and by a lack of water dilution and a stirring system. The water shortage played a crucial role in the breakdown of several biodigesters, especially in the area affected by the drought of 1998, because most of the farmers used a daily volume of water that was way lower than the one of the feedstock. As it is described in the literature research, under-dilution of the digester can also create a blockage for the biogas release at the bottom of the digester, and the formation of scum on the top surface [117].
Finally, the corrosion of the biogas appliances is another frequent operational issue (10 of 57) that can be easily prevented by regular cleaning of the gas jets in case of biogas stoves or of the gas valve in case of biogas lamp. The corrosion aspect is caused by the high water vapour content of the biogas that can react with the hydrogen sulphide generating ionic hydrogen and/or sulphuric acid, which is corrosive to metals. Installing a water trap and burying underground the outlet pipe in order to increase the water condensation is necessary wherever this issue occurs frequently [72].
All these issues are increased by the lack of knowledge of the farmers that showed a limited understanding of the operating aspect of the biogas plants. As a result, many minor technical issues can cause the total breakdown of the plant due to low technical skilled caretakers and the lack of follow-up service from the biogas companies.

It is possible to notice that mainly structure of a biogas plant is hierarchical, with an owner or manager that decides the tasks and the activity schedule for all the workers or family members. The decisions are taken from the top and the workers are not able to take the initiative without consulting first their superior. This is observed in the description of the woman role. The dominant family structure characterised by power hierarchy between family members based on the principles of sex, age and relatedness. In addition, the gender division of power is evident, with males having power over the females. This characterisation is also reflected in the internal management of the workers.
A professional attitude among the workers was very limited. They needed to receive constantly directions and tasks of the biogas activities. However, there was cooperation between workers even if they belong to different gender or age groups. This can be explained by a communitarianism value that characterises the whole African society. In certain cases, the motivation of workers is also influenced by the lack of interest of the owners towards the biogas technology for the reasons described in the previous paragraph.
A fatalistic attitude seems to be present in several cases. Due to the lack of a standardised manual for the biogas production, the manager and his workers couldn't follow a proper manual. In addition, they didn't have any tool or device to monitor the performance of the biodigester. This aspect is also affected by the lack of cooperation with the biogas service providers that after the installation of the plant, most of them left the area without giving to the users any instruction, training or practical manual to follow for proper maintenance of the system.
In most of the cases, the lack of a proper record system and a written schedule of the several daily tasks required for the running of a biogas plant shows typical synchronic time management of the activities. In one biogas plant, the activities were written in a blackboard,

located in front of the main door, in order to be followed by all the workers and keep the maintenance of the biogas plant monitored. As a result, this plant was still running after several years of optimal operations.

Despite the lack of support from the national government, the Ethiopian case study showed several organisations operating for the implementation of biogas activities. The Ethiopian Rural Energy Development and Promotion Centre is the central organisation that manages all the issues for the domestic energy systems. This organisation constructed several biogas plants in the country and they also managed the maintenance of that technology. In addition, the centre started to support the 'Bureau of Energy' for the development of the regional energy policy. The regional Bureau of Energy is an organisation that constructed small numbers (around 10) of domestic biogas plants in the several regions of Ethiopia under own management. In addition, they also involved in several studies for the energy crisis of rural households. These two with several other private organisations represented the core for the dissemination programme of biogas in the country. However, a coordinated national programme that will promote and diffuse the technology in both rural households and institutions is necessary. Moreover, some cases demonstrated the inability of some biogas service providers to communicate with the users in terms of maintenance training or simple follow-up service after the installation. This aspect promotes indirectly the distrust on people or companies that comes from different vertical networks since potential biogas users are more sceptical about the installation of a new biogas plant due to the lack of follow-up service by biogas companies.

4.1.7. Case description 4: Kenya

This case study, derived by the thesis research of Stephen N. Wamwea, describes a survey conducted in 2017 in Kenya of 176 domestic small-scale biogas plants [128]. The visited plants were located in the Kiambu (94 out of 176) and Embu regions (82 out of 176) where organisations like SNV Netherlands and KARI operated for the dissemination of biogas technology between 2008 and 2012. The 176 biodigesters were visited can be divided into two main types: fixed dome and plastic tubular digesters. In the Kiambu region, the majority of the plants were fixed dome where the installation of them was managed by the SNV organisation, while in Embu region the majority was plastic tubular thanks to the mediation of the Kenya Agricultural Research Institute (KARI). However, all the plants installed by KARI were failed in one or two years. The technicians interviewed gave reasons for the failures as blockage of the inlet pipe due to sand concentration in the feedstock, lack of technical assistance, irregular feeding, plastic perforated by moles from underground, animal interference, and other couldn't give a reason.

Through the interviewed with the official from the Ministry of Agriculture, Livestock and Fisheries, the author understood that the promotion and diffusion of biogas technology in Kenya have been very low due to a lack of support from the government, described by the total absence of government policy document about biogas in Kenya. In addition, organisations like SNV and KARI stopped installing biogas plants in Kenya due to a lack of financial support, subsidies, feedstock availability, and new research technical information. It is evident that tripartite cooperation between the government, the NGOs and the private sector is necessary to improve the biogas dissemination in the country.

In terms of performance, of all the 176 small-scale biodigesters visited, 126 were fully operating (around 72%), 44 were partially functioning (around 25%), and 6 were not operating (around 3%). Of the six failed biogas plants, one stopped operating after three years, three stopped operating after four years and two stopped operating after five years since the year of construction. The owners of the failed biogas plants in Embu county argued that the most crucial issues were the irregular feeding, the presence of sand and biomass particles in the substrate, the lack of technical assistance, the deterioration of the plastic tubular digester, the lack of protection from animals, and some of them didn't know the reason of failure. The owners of these plants decided to not fix the problems due to a lack of financial possibilities. The low percentage of not operating biogas plants can be considered a clear signal of overall proper management of the biogas technology in the country and a proper fixing in case of malfunction. Figure 4.12 describes the operating status of the biogas plants at the time of the visit (2006).

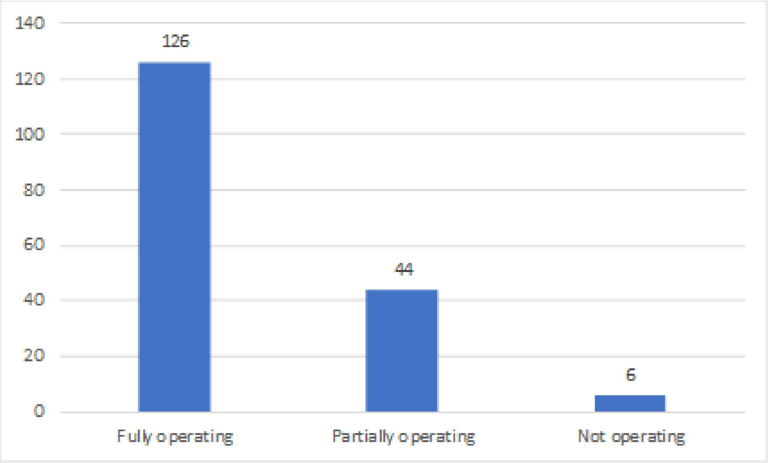


Figure 4.12: Operational conditions of biogas plants at the time of visit. Retrieved from: [128]

The majority of the biogas users owned up to 2 cows (74%) and 4-5 cows (70%) in Kiambu and Embu county respectively. After the installation of the biogas plants, 47 interviewed argued that they had to buy more cows in order to obtain enough feedstock for their biodigester. In Kiambu region, some farmers mixed the cow dung with some chicken, pigs, goats and sheep dung to fulfil the sufficient daily amount of feedstock necessary for the optimal performance of the system. The majority of biogas owners had enough feedstock to feed their digester (around 66%), while the others (34%) affirmed to buy extra feedstock from their neighbours, mixing the manure with water with a ratio of 1:1. For an average digester volume of 8 m^3 (120 of the 176 biogas plants had this volume), the owners fed their systems with around 30 kg of cow dung and 30 litres of water, with a typical frequency of two or three times a week. According to Ghimire [44], the minimum amount of feedstock required for a 4 m^3 digester is of 20 kg per day. However, some digesters that were operating in not optimal conditions were being fed with a varying ratio of water:dung. Some biogas users were using more water than dung as a compensation for the lack of enough manure, gen-

erating a thinner and diluted slurry at the outlet chamber. Moreover, these interviewees complained about the lack of instructions from the biogas providers and the worker's negligence as reasons for their irregular feeding of the digesters. During the cold season, the interviewed said that they reduced the amount of dung used to feed the digester due to the reduced bacteria activity to digest cold substrate, but they mixed the slurry generated with warm water and recycled the mixture back into the digester again. It was observed that the mixture of feedstock was first introduced in a drum with average dimensions of 1.25 m of height and 0.5 m of diameter, and then stirred with a stick until the mixture became viscous. Successively, the mixture was introduced into the digester through an inlet tank, made with bricks and concrete, connected with inlet pipe also made with concrete. As for the filtering system, the workers removed the big particles and other solid materials in the feedstock using hands and they couldn't measure the solid component in the feedstock at the end of the activity.
According to the author of the survey, 16 of all the 176 biogas plants had a design issue in terms of angle of the outlet pipe relative to the inlet one. The inlet and the outlet should be at the opposite extremes of the digester in order to ensure the full digestion of the substrate before being discharged out and to leave enough time to exhaust all the biogas produced. However, these 16 biodigesters presented the outlet pipe closer to the inlet, since the owners wanted to discharge the slurry in a specific place close to the inlet tank. This caused a low HRT of the substrate, so a low biogas production and a substrate not entirely digested.

In terms of gas usage, all the biogas users used the biogas produced for cooking, the 44% used it for cooking and lighting, and the 9% used it also for running the chaff cutters. The biogas stoves used by the households were either kerosene stoves modified for biogas pressure or biogas burners made locally. Due to a limited amount of biogas produced, some owners affirmed to use firewood as fuel when they needed to cook for a long time. Figure 4.13 describes the gas utilisation of the surveyed biogas plants.

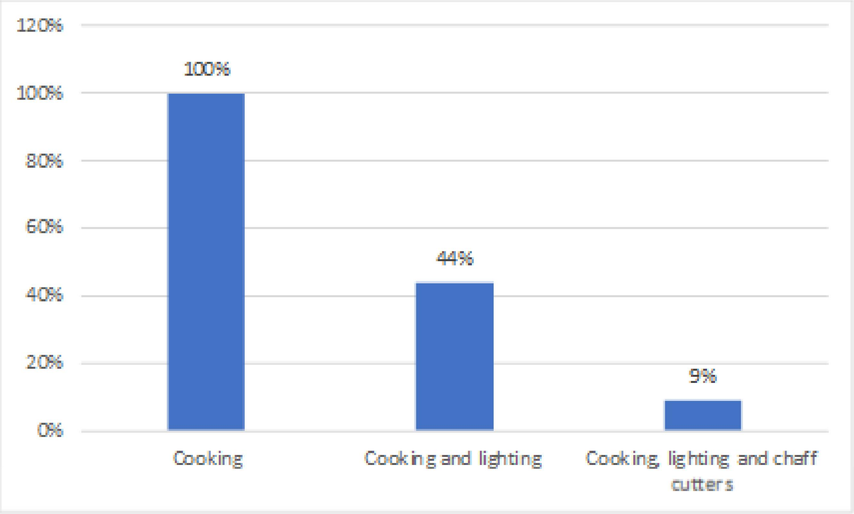


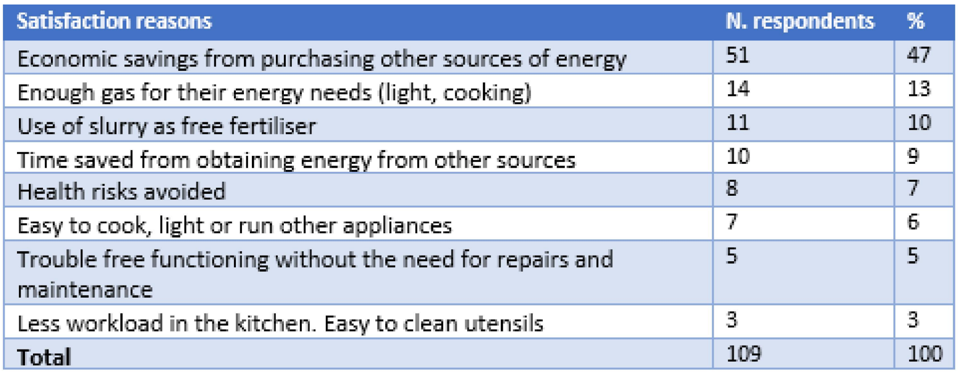
Figure 4.13: Gas utilisation of the surveyed biogas plants. Retrieved from: [128]

The outlet pipe of the biodigesters was typically composed by a metal pipe that connected the gasholder and the plastic pipe through a constantly open valve. The distance between

from the gasholder and the point of use of the biogas varied in the different plants ranging between 10 to 80 meters. One of the most occurred issue in the partially or not operating biogas plants was the presence of gas leakage (32%). At the time of the visit, the metal pipe and some part of the plastic pipe were not protected from being damaged by humans and animals. In addition, they were exposed completely to sunlight leading to the deterioration of the plastic, and most of the metal pipes were not painted to avoid the corrosion.
According to the technicians interviewed, two biogas plants failed also due to the lack of the water trap to avoid the water condense in the pipeline. As a result, some blockage of the outlet pipe was due to the water condenses. It was noticed in the visits that 37 of the 176 biogas plants used a desulphuriser, imported from China, to avoid the high concentration of hydrogen sulphide and the corrosion of the gas pipe, biogas stoves, lamps and other biogas appliances.
In terms of slurry, all the households in the Embu county used it to either do farming or to enhance the growth of fish feed in the form of algae and plankton. On the other hand, only 32% of the Kiambu households used the slurry due to a limited amount of arable land. The rest used to sell the slurry to the neighbours with larger farms at an average price of 50 US cents for 20 litres of bio-slurry. It was observed that the all the outlet displacement chambers, where the slurry was discharged by gravity, were not covered, for example using a metal sheet, and therefore rainwater and animals could enter accidentally into the digester.

The author cited also the total lack of a monitoring system for the temperature and the pH in the biogas plants visited. That was due to the lack of awareness and knowledge among local farmers, which did not want to spend more time and money on some instruments that they wouldn't be able to use. In addition, the lack of technical support and maintenance from the biogas companies influenced the total absence of regular control of these parameters.

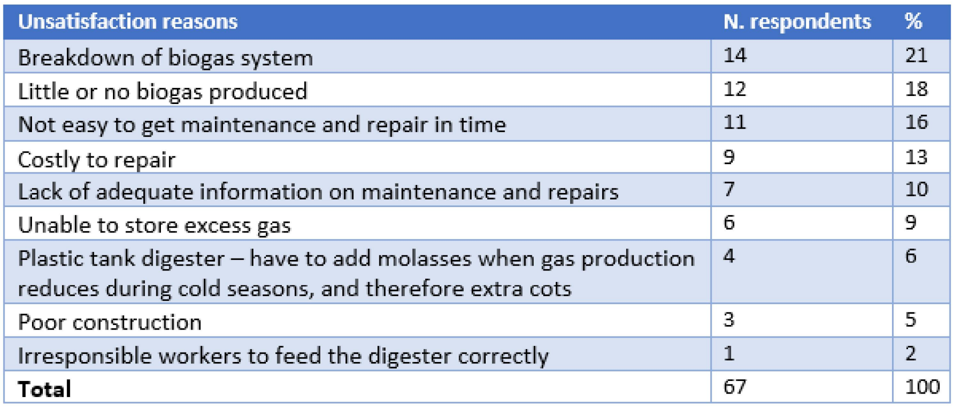
The figures 4.14 and 4.15 show the reasons given by the 175 local biogas owners either for being satisfied or not of using biogas. The owners satisfied were 109 while 67 were either partially or totally unsatisfied.



Satisfaction reasons	N. respondents	%
Economic savings from purchasing other sources of energy	51	47
Enough gas for their energy needs (light, cooking)	14	13
Use of slurry as free fertiliser	11	10
Time saved from obtaining energy from other sources	10	9
Health risks avoided	8	7
Easy to cook, light or run other appliances	7	6
Trouble free functioning without the need for repairs and maintenance	5	5
Less workload in the kitchen. Easy to clean utensils	3	3
Total	109	100

Figure 4.14: Satisfaction reasons of biogas owners. Retrieved from: [128]

The first figure shows that economic advantages, energy and time savings and health improvements were the major reasons of being satisfied for using biogas. The fact that environmental advantages was the last reasons can be explained by the not directly benefits obtained by the local farmers.



Unsatisfaction reasons	N. respondents	%
Breakdown of biogas system	14	21
Little or no biogas produced	12	18
Not easy to get maintenance and repair in time	11	16
Costly to repair	9	13
Lack of adequate information on maintenance and repairs	7	10
Unable to store excess gas	6	9
Plastic tank digester – have to add molasses when gas production reduces during cold seasons, and therefore extra cots	4	6
Poor construction	3	5
Irresponsible workers to feed the digester correctly	1	2
Total	67	100

Figure 4.15: Disappointment reasons of biogas owners. Retrieved from: [128]

The second figure shows that lack of adequate repair and maintenance of the biogas plant, lack of financial support and lack of information and awareness were the major reasons for being disappointed for owning a biogas plant. The two technicians interviewed added technical issues as the main causes of poor performance or failure of the biogas plants in Kenya. One of the main reason was the unequal ratio water/feedstock applied by the local owners. Another cause was the uncompleted digestion of the substrate before being discharged, observed from the generation of bubbles in the slurry. Gas leakage is the third main reason, generated by cracks formed in the dome and the piping system or through valves, for the reduction of biogas production. Finally, the lack of a stirring method of the slurry to remove the scum formed can be considered as a crucial factor for the failure of the biogas system.

In terms of internal management, the biogas plants presented at least one caretaker that maintained the digester. The people interviewed were the owners of the biodigesters. The author explained that the women were the most interested in biogas because it is mostly used by them for cooking and lighting. The use of biogas saved them up to 3 hours per day of workload and reduced their health risks for the use of fossil fuels as energy sources. However, the head of the families was in charge of making decisions and planning the activities for the running of the biogas plant, even if they used to avoid the hard work of the maintenance due to other commitments.

Fortunately, the maximum distance covered to collect water was 20 meters thanks to the presence of piping systems (Kiambu region) and dug boreholes (Embu region) as water sources. This aspect improved the internal management of other activities since the workers had more time to spend on other activities. A hierarchical and dominant family structure characterised the relationship between the several members of the family, with power structures divided per sex, age and relatedness. The decisions are taken from the top and they have to be accepted by the workers. This is also reflected in the power distance between the owner of the biodigester and his workers, where the lack of communication influences the professional attitude of the latter. The lack of professional attitude is also highlighted by the fact that "workers negligence" and "irresponsible workers" were con-

sidered respectively as one of the most important reasons of failure and one of the main reason of disappointment of owning a biogas plant. The author of the research argued that in some cases the owners could not give a motivation for the complete breakdown of the plant (16%).
According to the interviewed biogas users, the several activities for the optimal performance of the biodigesters were carried out at no specific time or frequency, they were achieved when it was necessary, such as when the biogas production was noticeably low. The reasons given by the author were the lack of knowledge of digester maintenance and the negligence of the workers. In addition, most of the users never checked the biogas plants for gas leakages along the pipelines or the valves, and they never cleaned the biogas appliances. On the other hand, all of the biogas plants presented a water trap and the biogas users always removed the outlet slurry to transport it to the farms. In addition, the author observed the lack of a record system in all the plants that led to the lack of constant feeding activities. As a result, the workers argued about a no clear definition of the several tasks in the biogas plants.

Most of the organisations actively involved in the promotion of biogas technology in Kenya are government agencies since the private sector is not so involved. Key organisations at the time of the visit (2017) were Special Energy Programme (SEP), the Ministry of Energy and Regional Development (MOERD), the Christian Intermediate Technology Centre (CITC), and the Tunnel Technology Limited (TTL). According to Wamwea [128], the promotion of the biogas technology in Kenya was quite low due to a lack of government policy dedicated to biogas. It was difficult to find a market for biogas products and there was a lack of cooperation between government, NGOs and the private sector.
In addition, most of the biogas users interviewed complained about a not efficient service provision from biogas companies. The follow-up services were not guaranteed due to the lack of an office location of the technicians and the lack of written agreements with them. Therefore, the biogas companies decided the time, the method and the cost of the installation. The survey showed also a lack of proper instruction by the biogas companies involved in the construction of the biogas plants, which led to a low knowledge about the operating and the maintenance of the technology from the biogas users. None of the owners interviewed received any operational manual or any instruction by the technicians, leading to a lack of confidence in carrying out basic repairs as soon as some minor issues occurred. The lack of follow-up service by them affected negatively the relationship between the users and the service company due to a lack of communication and also it affected the maintenance of the biodigester.

4.1.8. Case analysis 4: Kenya

The case study of Kenya is characterised by the 28% of the total surveyed biogas plants in partially or not operating condition. The low percentage of biodigesters that operate in not optimal efficiency, considering also only 3% of biogas plants totally failed, is the result of good management of the biogas plants where the owners and their respective workers followed precise operational guidelines. In addition, the author said that 69% of the plants fully operational had already been one time or more repaired or cleaned as soon as they stopped working. This indicates that either the average level of technical knowledge among

the owners was relatively higher than the other case studies or there was a relatively efficient biogas service from the organisations. However, the owners interviewed in the survey expressed the reasons for the malfunctioning and failures happened during the lifespan of their biogas plants. According to Wamwea [128], the lack of repair and maintenance, the lack of training, and undefined reasons were the most causes of failures in the case study.
Lack of maintenance is the most cited issue among the local farmers that experienced a malfunctioning or a complete failure of their biogas plants. This aspect can be observed through the fact that none of the 175 biogas owners monitored the technical parameters of their biogas plants such as temperature and pH. The first reason given by them is a too high cost of maintenance in terms of money, since the workers, the materials used to replace the failed part, and the alternative fuel used in absence of biogas, has an important cost compared to the initial investment, that most of the farmers cannot afford. The other reason is that most of the time the technicians were not available when the owners needed some assistance for their plants, leading to a lack of maintenance since the local farmers didn't know what to do for repairing the problem.
The lack of training is the second most cited issue among the local biogas owners. This aspect leads to not follow the recommended practice guidelines of the construction companies, that used to give them verbally after installation. Most interviewed argued that the government played the most important role in this aspect. According to them, the government failed to promote training programs or workshops on biogas technology among the citizens, in order to gain insights about the production process, the management of the plant, and to create trained personnel, and it failed to provide economic support (e.g. funds, subsidy, loans, etc.) such projects. This aspect reflects the lack of support from the government to local farmers that are willing to invest money, energy and time on this technology. However, the organisations involved in the technology promotion encountered some challenges such as negative attitude among local farmers towards the technology, due to the several activities required, and resistance to change, since most of the potential biogas users want first observe the benefit of biogas somewhere else in order to decide to invest on it.
These aspects induced to several operational issues encountered by the biogas plants of the case study. First, the lack of a cleaning system of the biodigester and the biogas appliances can induce to clogging or corrosion of the latter as it is possible to notice from the high number of biogas lamps clogged. Secondly, an unequal ratio of water and feedstock to the digester induced a reduction of biogas production. Lastly, the lack of filtering and stirring method led to the blockage of the piping system by the introduction of too big particles into the inlet pipe. All of these issues are caused first by a lack of practical knowledge on biogas among the biogas users that is a direct consequence of the lack of assistance by biogas companies and the lack of training.

It is possible to notice that most of the biodigesters were managed by women, and workers, since they were the one in charge of doing most of the household biogas related activities, such as collecting water, cooking, collecting fuel, etc. The fact that the head of the family, which represents also the biogas owner, didn't take part of the hard work of managing the biogas plant, is a clear aspect of the so-called 'status by position'. The person that performed the highest status position took decisions without doing hard work due to the power distance between different status levels. People aim to upgrade their status building stronger relationships with the boss, instead of being efficient in their tasks. This is also confirmed from the fact that one of the main issues encountered by biogas owners is the workers' negligence at work, such as for the feeding activities. The decisions were taken from the top and the workers have to accept them, even if it was possible to notice a sort of communication between the owner and the workers in the plant. All these factors describe a hierarchical vertical controlled form of power by the biogas owners.

A professional attitude among the workers was very limited. They needed to receive constantly directions and tasks. Biogas users argued that one of the points of their disappointment was the irresponsibility of the workers in feeding the digester. This is explained by all the aspects analysed in the previous paragraph. The workers' productivity decreases as soon as they are focused more on the relationships with superiors to obtain social status instead of their efficiency.

The Kenyan farmers also showed a typical 'resistance to change' in terms of adoption of the biogas technology. Uncertainty avoidance represents the adversity to take unauthorised initiatives due to a too high risk of going against the group, but also to take decision whose outcome is unpredictable. Risk-taking attitude is necessary in order to develop a proper business because this activity requires out-of-the-box thinking and innovation.

Time management was for most of the cases synchronic. Usually, workers didn't have a strict work schedule and they didn't record their activities. This is evident from the interviews of some users that expressed the lack of a written planning schedule of the activity. However, a correct division of some tasks such as water collection, dung collection, cooking was seen. The main reason is the lack of knowledge of the users of the biogas plants, which were not trained sufficiently by the biogas companies or by other regional programmes. Due to the lack of a standardised manual for the biogas production, the manager and his workers couldn't follow a proper manual. In addition, they didn't have any tool or device to monitor the performance of the biodigester. This aspect is also affected by the lack of cooperation with the biogas service providers that after the installation of the plant, most of them left the area without giving to the users any instruction, training or practical manual to follow for proper maintenance of the system.

Despite the lack of support from the national government, the Kenyan case study showed several organisations operating for the implementation of biogas activities. According to Wamwea [128], the promotion of the biogas technology in Kenya was quite low due to a lack of government policy dedicated to biogas, and a lack of cooperation between government, NGOs and private sector. This is a typical aspect of a vertical network society. Group members build their relationship based on the aim of acquiring status in the individual competition with others and on the pursuit of personal interest, for instance when local owners provide a service and favours to their clients in return for loyalty and help. Moreover, in a society where vertical networks are dominant, obtaining the right contacts is considered the fastest and easiest way to influence the government bureaucracy to get licences, tax regulations or just cooperation. Some cases demonstrated also the inability of some biogas service providers to communicate with the users in terms of maintenance training or simple follow-up service after the installation. This aspect promotes indirectly the distrust on people or companies that comes from different vertical networks since potential biogas users are more sceptical about the technical support of biogas companies after the installation of the plant.

4.1.9. Case description 5: South Africa

This case study describes my experience spent in South Africa, specifically in Johannesburg where I conducted interviews to local farmers that owned a biodigester and biogas expertise. The biogas expertise was the Director of Energy Department of the Johannesburg Municipality, the Manager PEETS of the University of Johannesburg, the CTO and Project Manager of Iber Ltd., the Senior Researcher of Department of Civil and Chemical Engineering at UNISA, and the CEO of Moto Maloti Resources. There were some limitations to the research conducted in SA. Firstly, the information obtained from the interviews cannot be guaranteed to be 100% trustworthy. Misunderstanding of the questions or too subjective answers can influence the reliability and validity of the description. Secondly, there was a limitation of time and transport to conduct the research through the area around Johannesburg. The sample size was 11 interviewees, with 5 small-scale biogas owners interviewed located in Johannesburg and Limpopo. The visited plants in Johannesburg were two standard floating-drum digesters of 8 m^3 owned by local farmers and a prefabricated plastic fixed dome digesters (PBD) of 5 m^3 constructed in the garden of a Primary School in Soweto, while the plants located in Limpopo were two plastic tubular dome digesters of 12 m^3.

In contrast to an onsite-constructed digester (OCD), the PBD relies on materials, no locally produced, with special physical properties to avoid construction issues such as gas leakage and structural cracks. The fixed dome type of PBD, which is the one adopted in the biogas plant visited, has several advantages, such as mobility, long-term durability, and high productivity. The system can be transported and removed easily due to its low weight, and it has good corrosion resistance to all the organic acids generated during the anaerobic digestion. The installation is mainly composed by the earth excavation, which takes the majority of the time and energy. The disadvantages of this specific type of biogas system are the high initial investment, that requires the financial support of government organisations or NGOs, the structural problems in case of low strength of the groundwork, and the limited choice for the local owners in terms of digester volume [24]. Figure 4.16 and 4.17 show respectively a household PBD that is being installed in a project site in Vietnam and the plastic tubular dome visited in Limpopo.

Figure 4.16: Installing prefabricated biogas digester at a project site in Vietnam. Retrieved from: [24]

Figure 4.17: Plastic tubular dome digester in Limpopo.

In terms of performance, 4 of 5 plants were partially operating, while the other was just used for the generation of slurry as organic fertiliser. None of the biogas plants had a biogas meter in order to control the amount of biogas produced, but through the amount of hour in which the biogas was used, it was possible to determine that optimal biogas production was not obtained by any plant. A household on average spends 2.5-3 h per day for cooking (average of 5 members). All of the biogas plants used the biogas just as cooing fuel through the application of biogas stoves or kerosene stoves adjusted to the biogas pressure. 3 out of 4 of the operating biogas plants, was not able to produce enough gas to cook at least 2 hours, while the other used the biogas just for cooking and the rest is flared. Table 4.3 describes the operating status of the biogas plants at the time of visit with some remarks per each plant.

System	Installation year	Size digester $[m^3]$	Type of feedstock	Status	Remarks
1	2017	5	Food waste	Partially operating	Gas meter broken; not constant feedstock quantity; undefined cause of low yield
2	2017	12	Cow dung	Not use	Biogas completely flared; gas leakage from the outlet pipe
3	2017	12	Pig manure	Partially operating	Gas leakage from the outlet pipe
4	2016	8	Cow dung	Partially operating	Not constant feedstock quantity; gas leakage from the outlet pipe
5	2016	8	Cow dung	Partially operating	Unequal ratio water/dung; substrate not entirely digested

Table 4.3: Description of the visited small-scale biogas plants, including the year of installation, the size, the type of feedstock used, the status, and some remarks about operating issues

It is possible to observe that all the biogas plants were installed between 2016 and 2017, so they are very recent compared to the year of visit (2018). The two systems located in Limpopo were installed by a construction company in Johannesburg, while the one constructed in the Soweto school was installed by an NGO called GenderCC, and the two floating domes in rural area of Johannesburg were constructed by the local farmers in collaboration with the University of Johannesburg and several students from TU Delft.

In general, the effluent is used in all the biogas plants visited as organic fertiliser. In the primary school, the slurry is then diluted with one litre of water due to its high solidity, while in 3 other plants (2 floating-drum and 1 plastic tubular dome) the effluent was not completely digested, observed from its bed smell and the too liquid consistency. For these reasons, some farmers claimed some instruction in order to understand if the slurry is digested or not. The use of chemical fertiliser is increasing in South Africa due to the degradation of the soil, with the aim to maintain constant soil productivity. According to the CEO of Moto Maloti Resources, the women are in charge of taking care of the land, and they used around 12 kilograms of chemical fertiliser per 100 m^2 of land twice per month (a production cycle is composed by two months). In addition, the CTO of Iber Ltd. affirmed that the effluent represented for them a stream of revenue, with the too liquid consistency issue. They used to take out part of the nitrogen content (too high) and to dry the effluent in order to be able to sell one kilogram for 500 RAND (around 30€).

For the temperature, an average value of 31.5 °C is shown, which is slightly below the optimal value but it is perfectly comprised into the mesophilic range (30-45 °C). Local biogas owners didn't pay attention to this factor since even in winter the temperature doesn't decrease so drastically. Some farmers covered the digester with a plastic coat in order to

create a sort of greenhouse effect and keep the temperature as much constant as possible. Another solution was to dilute the feedstock with warm water to increase its temperature.
The interviewers observed that the main issues encountered in their biogas plants were: gas leakage in the outlet pipe, discontinuous feeding, and unknown problems. The gas leakages were caused mainly by a poor piping system that led to heavy biogas losses when the latter passed through the cleaning systems, such as CO_2 and H_2S removal system. Some farmers argued that they needed to pump manually the biogas through the plastic pipe in order to give it enough pressure for cooking. In addition, the biogas stoves were in very bad condition at the time of visit, that represented a poor cleaning activity of the biogas appliances leading to corrosion and gas losses. Moreover, some biodigesters had problems with the condense water that blocked the gas hose and they were fixed with the application of an empty plastic water bottle in the middle of the outlet pipe.
The feeding system most of the time is not constant. The lady in charge of the biodigester in the primary school affirmed that she used to feed it every day with almost 20 litres of water and 20 kilograms of food waste from the school. The problem is that during the summer season, when the school is closed, it is hard to feed the biodigester every day, so it can happen that the feeding frequency changes to once every 3 days or more. Moreover, she was the only person who knew how to maintain a biodigester and in case of her absence, due to fever or personal commitments, no one would be able to feed the biodigester. In one of the biogas plant in Limpopo, the owner said that at the beginning they were feeding the digester with 50 kilograms of manure every three days, but due to low biogas usage and low production of manure, they reduced the amount of feedstock to 15 kilograms every three days. In general, workers don't have the proper knowledge to know why a constant feeding of the system is so crucial for the performance. They just do what other people (owner, technicians, experts) tell them to do, but as soon as they stopped to receive guidelines they are not able to work independently.
Lastly, most of the biogas users didn't answer very accurately to the operational questions because they did not have enough technical knowledge and they couldn't monitor the performance of the biodigesters, especially for the one in the primary school since it was underground. The lack of knowledge was also enhanced by the lack of proper instruction given by the biogas companies once the system was installed, and by the lack of a practical manual with the activities necessary for the correct maintenance.

In terms of internal management, the biogas plants presented at least one caretaker that maintained the digester. The people interviewed were the owners, or in one case just the person in charge of the technology. It was evident a hierarchical management style of the workers due to an unequal relationship between the superior and the subordinate. The owners gave weekly instructions on the activities that have to be done for the running of the biogas plant, especially for the feeding step that it was not constant. However, the communication between the workers and the supervisor was present and the latter was very open to listening to the workers' opinions, even if at the end the owner is always the only one who takes the decision. In one case, the three employees were free to express their idea, but due to their low education level, they were not able to express useful innovative solutions. In this case, the workers just had learned the practical work in the farm with the farmer's guideline and they integrated that practical knowledge with theoretical lessons in order to understand the aspects of the biogas technology. In the other two biogas plants, the workers are managed by the owners and they received daily tasks that they need to achieve in time. In this way, the workers are controlled and they cannot forget to do the basic activities for the good performance of the biodigesters. However, the motivation of the employees who are in charge of maintaining the digester, except for the one who got the final result (biogas production), can decrease, since they couldn't see the result of their work. A monitoring system could help also to increase the motivation of the workers, showing them the importance of their activities for the overall performance of the biodigester. Unfortunately, all these activities were not recorded in a notebook or in a blackboard, but they were given and controlled verbally.

According to the CTO of Iber, the biogas owners couldn't hire trained workers due to the high cost and the very few amounts of biogas experts in the country. The only solution was to train workers on-site, investing in their practical training, but with the uncertainty of their loyalty for the company. The European mentality of feeling responsible for the plant performance, since the business of the biogas owner is also positive for the workers' wages, was not present among local workers. People were more focus on getting enough money for their family, independently on the job carried out. The second farmer in the rural area of Johannesburg had 10 employees and its relatives help him to manage the workers and the biogas plant. He cannot trust the employees because they were easily economically corrupted by thieves or other groups in order to receive information or directly money of the farmers. However, good communication was present and the workers seemed to have a quite motivated attitude.

The lateness of the employees seemed to be quite usual in the biogas plants. However, they could be penalised if they didn't have a valid reason or if they were late several times. At one visit, two workers of that plant were missing and the owner said that they were allowed to miss the workday for personal commitments and he would subtract the monetary value of the time lost from the salary if the delay would be frequent. In addition, a planning scheme or a record system were missing in all of the biogas plants and this was often leading to not feeding the digester every day. Some owners explained the lack of a physical scheme with the fact that they did the planning from the top of their head.

According to the Director of the Energy Department, the bureaucracy in South Africa was still very high leading to wait a long period of time for obtaining licences for the business. With the introduction of private sector generation of energy, also called Independent Power Producers (IPPs), the government aimed to establish new regulations, composed by rules and guidelines that should encourage the development of new renewable energy projects. Due to the constant energy crisis affecting especially rural farmers, the Department of Energy, in collaboration with key stakeholders, were trying to accelerate the participation of IPPs in the energy sector, reducing also the bureaucracy time. However, this reduction was not enough due to also a too high number of Departments in the Municipality of Johannesburg. According to a local biogas owner in Johannesburg, to get the licence to build a biodigester of at least 1 ton per day of manure it is necessary to wait 5 years for the high bureaucracy.

Another aspect observed is that in the Department of Energy, there was no biogas expert. For this reason, as soon as they have to start a biogas project, they need the support of universities and biogas stakeholders. After the installation of one of the biodigesters in the rural area of Johannesburg, the owner organised a presentation and a workshop in order to show the functioning and the benefits of the biogas system to local farmers and government officials.

According to the Manager of PEETS, the investments made by the government had to be monitored because the issue was not to find capital to finance biogas projects, but most of the time this capital didn't reach the impact it wanted, due to bad management of the investments. The lack of biogas regulations and standardisation, most of the investments made by the government were burnt for either a poor construction of the biogas plants or poor maintenance, with the same result of the failure of the plant.

One of the biggest issue described by all the interviewees was the low education level of local farmers and their lack of awareness of the biogas technology. In rural areas, most of the workers (more than 90%) didn't finish the primary school, and the owners had to spend a lot of energy and time in order to train them on their work activities. Some biogas companies installed and gave the biodigester finished to the local community, without involving them into the construction. As a result, local people were not able to maintain the technology, since they couldn't see how it was constructed, and they didn't receive any instruction from the biogas providers. Some NGOs and government organisations were involved in the promotion of biogas, through the development of the workshop, and simple training sessions where the farmers or local entrepreneurs could see the benefits in terms of environment, finance and energy. Women were the most enthusiastic about biogas technology because they could appreciate more the benefits obtained from a possible adoption of it. They were the member of the family who had taken care of the house and the garden, including the collection of firewood, chemical fertiliser, collection of water and the harvesting of vegetables. Men were usually the family's member who went to the city centre to find a good job and earn enough money for the family. For this reason, NGOs were focused on gaining the interest and the approval of the wives of local communities or in general their women. According to local farmers, the practical demonstrations on the site of the technology were the most efficient way to promote the technology. A person who owns an operating biodigester would be an example for local people that this kind of technology brings several advantages and benefits to the users. However, the majority of the people were just interested in the financial benefits that the technology could bring, without taking into consideration all the other aspects.

Moreover, a lack of follow-up service by them affected negatively the relationship between the users and the service company due to a lack of communication and also it affected the maintenance of the biodigester. Some owners expressed their ignorance about the condition of the digesters because they did not receive any instructions or manual that could explain how to monitor the performance of the plant.

4.1.10. Case analysis 5: South Africa

The case study of South Africa is characterised by the 100% of the total visited biogas plants in partially operating condition, since all of them presented a malfunction and a not optimal biogas production. On the other hand, none of them had failed, which represents a positive signal for the general maintenance of the biogas plants in South Africa. These biodigesters experienced several operational problems during their lifespans such as gas leakage and discontinuous feed, and technical issues such as water condense blockage of the inlet pipes and biogas appliances corrosion.

Gas leakage represents the most occurred issue in the small-scale biogas plants visited in South Africa (80%). This problem is mainly generated by the poor quality of the plant structure. The adoption of poor materials during the construction of the biodigester plays an important role in the avoidance of gas leakage. It is important to mention that the materials used to install a biodigester primarily depend on the soil properties, and the local availability [128]. Sometimes the materials locally available don't have the quality requested for the construction of a biodigester that needs to be pressure-, water-, temperature-, and corrosion-resistant. This aspect was observed in the two floating-drum digesters in the rural area of Johannesburg, where water leakage inside the digester was experienced due to the presence of cracks or fracture in the gasholder surface. Another factor for them was also the poor construction of the outlet pipe which was connected with the cleaning system through plastic tubes. As a result, the biogas used by the biogas stoves was very limited and not sufficient to be used for cooking. However, the use of non-local materials increases the investment cost of the plant due to additional costs of transportation, and it doesn't involve the local community in the construction leading to a lack of knowledge and interest among biogas users. In the primary school of Soweto, the prefabricated biodigester led to a deep lack of knowledge among the local people, except for the woman in charge of the maintenance which attended training sessions organised by an NGO, where she received basic instruction. As a result, the gas leakage couldn't be detected due to the position of the digester completely underground, and the lack of knowledge among local people.

Another factor of gas leakage is the no consumption of biogas by the users, as the farmer in Limpopo. The reason was that the user prefers to avoid technical problems for the use of biogas adopting traditional fuels. As a result, the farmer flared directly the biogas produced.

The other biggest challenge for the performance of the biogas plants was the discontinuous feeding system. Most of the farmers followed the instruction given by the biogas providers but as soon as they encountered some uncommon situations they changed the feed frequency and quantity. For example, in primary school, due to summer holidays, the biodigester stopped being fed for two months. In Limpopo, a biogas user decreased the feeding quantity due to the lack of sufficient manure and the no consumption of biogas. All these factors are characterised by a deep lack of knowledge of the biogas technology. The biogas owners should receive the necessary education, from the government organisations or the NGO involved in the installation of the biogas plants, to be able to understand the basic requirements for the good performance of the biodigester, such as a constant feeding of the system. In addition, the biogas companies that are in charge of constructing the biodigester should first analyse the plant potential in terms of feedstock and water availability.

Another issue occurring quite often in the case study is the blockage of the inlet pipe. In two plants, the owners used more water to dilute the feedstock in order to make it more liquid and with the adoption of a wooden stick they stirred and enhanced the input inside the digester. The presence of a proper stirring system, with sufficient water availability, was fundamental for the running of the biogas plants. The water shortage played a crucial role in the breakdown of several biodigesters, especially in the area affected by drought as the southern part of the country in 2018.

Finally, the corrosion of the biogas appliances is another frequent operational issue that can be easily prevented by regular cleaning of the gas jets in case of biogas stoves. The corrosion aspect is caused by the high water vapour content of the biogas that can react with

the hydrogen sulphide generating ionic hydrogen and/or sulphuric acid, which is corrosive to metals. Installing a water trap and a H_2S cleaning system is necessary wherever this issue occurs frequently [72].
All these issues are increased by the lack of knowledge of the farmers that showed a limited understanding of the operating aspect of the biogas plants. As a result, many minor technical issues can cause the total breakdown of the plant due to low technical skilled caretakers and the lack of follow-up service from the biogas companies.

It is possible to notice that the internal management of most of the biogas plants was hierarchical, with an owner or manager that decides the tasks and the activity schedule for all the workers or family members. The decisions are taken from the top and the workers are not able to take the initiative without consulting first their superior due to their low education level. This is observed in the description of the management of the workers by the biogas user in the rural area of Johannesburg. In addition, the gender division of power is evident, since the CEO of Moto Maloti Resources affirmed that the male members of the family cannot take care of the house and the field but they need to find a proper job in order to maintain the family. This characterisation is also reflected in the internal management of the workers. A status by position characterised the biogas plants, where who perform the highest status position in the group, so the biogas owner, has to make decisions without doing the hard work of maintaining personally the plant due to the power distance between different status level. In one case, the workers were managed by the farmer through a manager, which was called weekly by the biogas owner when he was working outside the farm. In this way, the power distance between the workers and the superior, and a lack of communication between them was highlighted. In another case, even if the decision were taken by the owner and the tasks were divided among the workers, every week the owner used to organise a meeting with all the workers in order to plan the schedule for the entire week. It is very difficult to build a trust relationship with the workers but good communication and a more egalitarian structure can enhance the motivation of the workers. As a result, more initiatives can be taken by them due to a higher level of practical knowledge.

A professional attitude among the workers was very limited. They needed to receive constantly directions and tasks of the biogas activities. However, there was cooperation between workers even if they belong to different gender or age groups. This can be explained by a communitarianism value that characterises the whole African society. In certain cases, the owner had to control the productiveness of the workers through daily calls with the responsibility of that specific group of workers. This is the clear evidence of a low professional attitude among workers that was going to influence negatively on the biogas plant production.

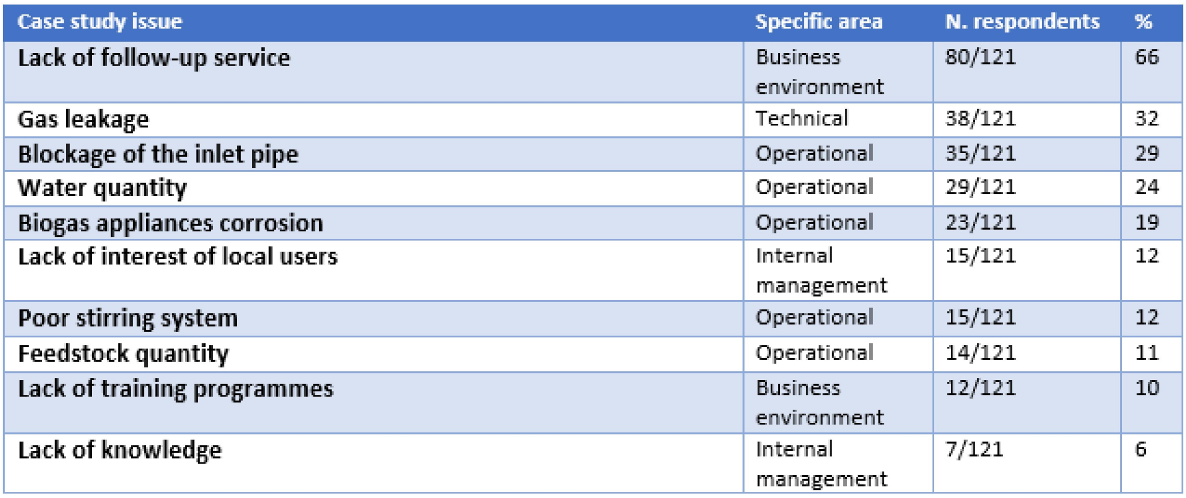
A fatalistic attitude seems to be present in several cases. Due to the lack of a standardised manual for the biogas production, the manager and his workers couldn't follow a proper manual. In addition, they didn't have any tool or device to monitor the performance of the biodigester. This aspect is also affected by the lack of cooperation with the biogas service providers that after the installation of the plant, most of them left the area without giving to the users any instruction, training or practical manual to follow for proper maintenance of the system. Time management was for most of the cases synchronic. Usually, workers didn't have a strict work schedule and they didn't record their activities. This is evident from the interviews of some users that expressed the lack of a written planning schedule of the activity since they used to plan everything in their head and then tell it to their workers. The main reason is the lack of knowledge of the users of the biogas plants, which were not trained sufficiently by the biogas companies or by other regional programmes.

Despite the lack of support from the national government, the South African case study showed several organisations operating for the implementation of biogas activities. GenderCC and Moto Maloti Resources represented two NGOs that managed the promotion of the biogas technology and the installation of biogas plants around Johannesburg. However, a coordinated national programme that will promote and diffuse the technology in both rural households and institutions is necessary. From the interviews, it was highlighted a lack of knowledge on biogas among the government officials which led to a lack of proper regulatory framework and policy for the promotion of biogas projects. In addition, the bureaucracy is still high in South Africa, which affected the interest of farmers on building biodigesters since they need to wait some years to get a licence. This is a clear aspect of a society dominated by vertical networks, where obtaining the right contacts and being accepted by the appropriate vertical networks are considered the fastest and easiest way to influence the government bureaucracy to get licences, tax regulations or just cooperation. In this way, investment in terms of time and money is necessary. Moreover, some cases demonstrated the inability of some biogas service providers to communicate with the users in terms of maintenance training or simple follow-up service after the installation. This aspect promotes indirectly the distrust on people or companies that comes from different vertical networks since potential biogas users are more sceptical about the installation of a new biogas plant due to the lack of follow-up service by biogas companies.
Finally, the lack of education on biogas among local people explained a not sufficient promotion of the technology from institutions, government and private sector that should invest more on training sessions and workshop in order to make people aware about the benefits that could bring this technology. According to professor Malan of the Department of Development Studies at UJ, one of the best medium to share knowledge among farmers is what he called "Social Innovation Events", where local entrepreneurs and experts meet all together and create a community of practice (a social innovation system). They are on the ground events, with the community of practice and unfortunately not enough media and materials to broaden these events in other regions. The drawback of this type of events is the lack of scientific and academic footprint and the use of ICT in order to acquire more appeal and followers from everywhere. Organising some discussions during these events is very effective because local communities feel called to purpose by these topics and they can participate more actively asking questions and sharing experiences. Finally, even individual booklets could be useful for spreading the knowledge to each farmer.

4.2. Issues analysis

The previous sections described and analysed the operational aspects that are commonly observed in the malfunctioning small-scale biogas plants in SSA. In addition, a socio-cultural description was included in the case study analysis in terms of internal management and environmental business in order to study the connection between these factors and the performance of a biogas plant. What becomes clearly visible is that operational issues are not just caused by operational or technical factors. They also are indirectly generated by socio-cultural aspects that characterise the internal management and the business environment that characterise the biogas business in SSA, but sometimes these interconnections are not so evident in the descriptions so they are difficult to be analysed without resulting in speculation. In this section, the ten most frequent issues experienced in the case studies will be evaluated focussing on the relationship of cause and effect that interconnect the specific issue with the other parameters of the evaluation framework.

By analysing the individual case studies, a list of most occurred issues described previously can be developed. Figure 4.18 shows the most ten occurred issues, including the type, and the frequency. It was considered the number of biogas plants that were partially or not operating in the case studies (121) as the total amount of valid interviewees in the issue evaluation. As it can be noticed, the sum of all the issues doesn't make the total amount of respondents because most of them gave more than one issue as a reason for failure. In addition, the issues are categorised per each area that composes the evaluation assessment. In this way, it is possible to analyse the most affected area and the respective connection between the different area.



Case study issue	Specific area	N. respondents	%
Lack of follow-up service	Business environment	80/121	66
Gas leakage	Technical	38/121	32
Blockage of the inlet pipe	Operational	35/121	29
Water quantity	Operational	29/121	24
Biogas appliances corrosion	Operational	23/121	19
Lack of interest of local users	Internal management	15/121	12
Poor stirring system	Operational	15/121	12
Feedstock quantity	Operational	14/121	11
Lack of training programmes	Business environment	12/121	10
Lack of knowledge	Internal management	7/121	6

Figure 4.18: Overview and categorisation of the most occurred issues in the case studies analysed.

Is it possible to notice that the area most affected by malfunction or problems is the 'operational' area, that is mentioned 116 times in the case studies, followed by the 'business environment' area with 92 mentions, the 'technical' area with 38 mentions, and the 'internal management' area with 22 mentions. The lack of follow-up service is considered as a business environment issue since the relationship between the biogas users and the biogas companies is considered as an external factor to the biogas plant affected by the cultural structure of the society. Gas leakage is considered a technical issue connected with the plant structure, as it is described in the literature research. The blockage of the inlet pipe is considered as an operational issue since it is mainly caused by a lack of a proper filtering and stirring system in the biogas plant. The biogas appliances corrosion is considered as an operational issue since an insufficient cleaning system is the main effecting factor for this type of issue. The lack of interest of the local users is strictly connected with the internal management since it can be seen as an internal factor of the maintenance of the biogas plant (as it is described in the next section). The same line of reasoning is applied for the lack of knowledge because it is considered a factor strictly connected with the owner and the workers of the biogas plant. The lack of training programmes is considered a business environment issue since it is an external factor, in which government and NGOs are involved, that influences successively the other area. Figure 4.19 shows the share of the issues per each area.

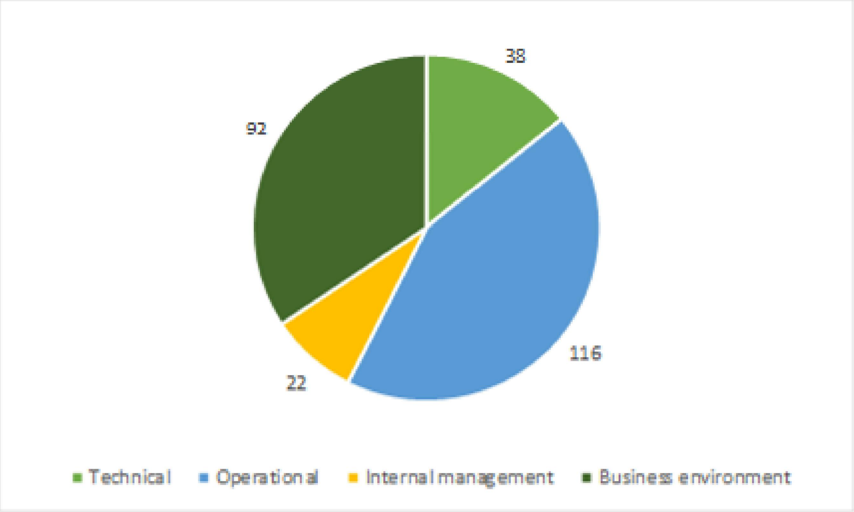


Figure 4.19: Overview of the area share of the 10 most occurred issues in the case studies

In the next section, the several issues will be evaluated in order to identify them in terms of the model's parameters previously described, and to analyse the connection between the several parameters.

4.2.1. Issues evaluation

Lack of follow-up service by biogas companies

Findings of the case study analysis shown that the biggest issue experienced by biogas user in SSA is the lack of follow-up and regular maintenance by service providers. Around 80 out of 121 surveyed people (66%) involved with malfunctioning biogas plants responded to this factor as a big challenge for the success of a biogas plant. Is not possible to give a specific explanation for the lack of maintenance by biogas service providers in the case studies analysed since all the surveyed people were either users, owners, or workers of biogas plants and not responsible of a biogas company. According to Ghana's case study, the owners did not make any written agreements with the biogas companies to receive any follow-up services after the installation of the digester. In this way, the biogas companies were not committed to providing the service and, due to a lack of communication between the users and the companies, the biogas plants didn't receive proper maintenance. As a result, most of the digesters that experienced a malfunction risked to remain unfixed and then abandoned.

The obvious consequence generated is poor maintenance received by the biodigester. The users usually don't have sufficient technical knowledge to evaluate an operational problem and to come up with a technical solution. The biodigester does not require a lot of maintenance during its lifespan, but sometimes who is in charge to control its performance should be able to fix minor technical issues that can occur such as small cracks in the dome, gas leakages through the gasholder or gas connections, and cleaning the biogas appliances. The lack of maintenance by service providers does not only lead to poor maintenance of the biodigester itself but also generate a profound lack of interest or reluctance among the local community about the adoption of biogas technology. Not only the number of failed biogas projects is very high compared to other countries, highlighting the barriers and drawbacks of this technology instead of its numerous benefits, but also potential biogas users don't see any cooperation with biogas companies, which should represent the first actors involved in the promotion of the biogas in SSA [105]. As a result, the lack of anonymous trust broadens the distance between customers and suppliers, or users and biogas companies, because trust and responsibility are always limited to the family or to the vertical network [52]. As soon as the installation of biodigester is completed and the construction company received the payment from the users or the government, some of them stopped to cooperate with the local people without providing them with any follow-up service or training.

Observing the indirect evidence given by the case study description about the internal management and the business environment of the biogas plants, a possible explanation is given about this specific issue. The lack of maintenance service from biogas companies can represent an indirect consequence of the presence of vertical networks in the SSA society. In the vertical networks, building relationships based on cooperation and open trust between members of different groups is very difficult and it requires money and time investments [47]. This condition leads indirectly to a generic distrust between people or companies that comes from different vertical networks since potential biogas users are more sceptical about the installation of a new biogas plant since they observe a general lack of technical support by biogas companies.

Gas leakage

Gas leakage represents the second most occurred issue in the small-scale biogas plants analysed in the previous section with 38 complaints out of 121 surveyed biogas users (32%). This problem is mainly generated by three aspects, poor quality of the plant structure, the no-use of the biogas produced and a lack of maintenance of the gasholder. The first cause can imply three main factors, which are the age of the plant, the construction materials adopted and the design of the biogas plant.

The age of the plant can represent a crucial factor to consider, especially when the plant has more than 10 operating years. It is not a coincidence if 100% of the biodigesters in Ghana with more than 10 years of operation are affected by gas leakage or not operating at all. The longer a biogas plant is running, the more frequent problems of gas leakage occur [25].

The adoption of poor materials during the construction of the biodigester plays an important role in the avoidance of gas leakage. It is important to mention that the materials used to install a biodigester primarily depend on the soil properties, and the local availability [128]. Cracks of gasholder due to the use of poor quality materials has been observed in the Ethiopia case study, wherein one plant the biogas construction company adopted low-quality brick and concrete due to their low cost. Sometimes the materials locally available don't have the quality requested for the construction of a biodigester that needs to be pressure-, water-, temperature-, and corrosion-resistant. However, the use of non-local materials increases the investment cost of the plant due to additional costs of transportation, so much that local users are induced to use cheaper local materials. As we have noticed in the second case study, a proper design of the biogas plant is fundamental in order to avoid gas leakage and other technical issues. According to Lohri [71], the gas leakage was mainly occurring through the rim between the gasholder and the digester with around 22% of the total biogas produced wasted into the atmosphere. He noted that an improper proportion between the gasholder and the digester sizes was generating biogas losses. The same author observed a reduction of biogas losses to 14% using a different type of tank produced by another biogas company. In addition, the junctions of the outlet pipe are crucial regarding biogas losses. The most typical type of gas leakage is the one through gas pipes [25]. Any loose joint can lead to gas leakage.

Another big factor of gas leakage is the no consumption of biogas by users. In Ghana case study more than 90% of the total gas leakage issues occurred is due to the no application of the biogas produced that is released freely into the atmosphere by the caretakers. This is caused by several factors, such as financial, since farmers or institutions cannot afford the purchase of biogas appliances, technical, since users prefer to avoid technical problems for the use of biogas adopting traditional fuels, and knowledge, due to the lack of on-site training on the construction, operation, maintenance, and servicing of biogas generating systems.

The last direct origin of gas leakage is the lack of maintenance of the gasholder. The deterioration of the plastic balloon gasholder can be considered one of the causes of gas leakage and it is experienced by two floating-drum digesters in Ghana case study. Both are constructed in 1994, which is 15 years before the realisation of the survey. Aged biogas plant and direct exposition to solar irradiance are the main factors for plastic gasholders and to avoid this kind of damage a roof that protects the bag from direct solar radiation is necessary [124]. Moreover, a fence can be useful to protect against damage by animals [124].

Gas leakage doesn't affect negatively just the biogas production but also it represents a health hazard for a household in case of inhalation of the gas and a potential cause of fire explosion since, under the specific concentration of biogas, the gas can be explosive in contact with air. In addition, in case of biogas leakage in the air, the environment is seriously damaged by the release of around 60% of methane (the average methane concentration of biogas) which is one of the most dangerous greenhouse gas.

In the case study descriptions, detailed information about the internal management and the business environment of the biogas plants in that specific context were leaking. Therefore, a possible explanation of this issue in terms of the aforementioned aspects can be developed taking into consideration indirect evidence and information gathered during the case study analysis. Gas leakage can be generated not only by a lack of appropriate maintenance of the biogas plant but also by a lack of awareness of the biogas technology. In the previous paragraph, the lack of specialists in biogas technology among biogas service providers has been explained as one of the reasons for malfunctioning. However, the maintenance of the plant is mostly affected by the level of technical education of the owner and user of the technology. In the case study of Ethiopia, many local farmers showed limited awareness of the functioning of a biodigester. In Ghana, most of the digesters are used for sanitation purpose while the biogas is occasionally consumed. Most institutes and the local farmers with a biodigester installed were not aware of what biogas is, how they could use it and what were the benefits and limitations of it. As consequence biogas is not commonly used and properly handled but released into the air without flaring (burning).

Blockage of the inlet pipe

The blockage of the inlet pipe is one of the most frequent issues in a small-scale biogas plant, with 35 complaints out of 121 surveyed biogas users (30%). In the Tanzanian case study, this is the most occurring issue due to the lack of a filtering system, that could separate big particle or inert materials like plastic, sand or rocks from the rest. Another reason for the blockage of the inlet pipe is the lack of an appropriate cutting and diluting system for the feedstock. In addition, the author of the same case study report suggested a replacement of the T-connector at the lower extremity of the inlet pipe with a swift-elbow one, that can enhance the flow of the feedstock inside the digester, and the installation of a 2"-ball valve to the connector in order to improve the removal of blocking material. Also in the Ghanaian case study, more than 20% of digesters experienced this problem which caused basically by the introduction of materials with higher dimensions than the diameter of the inlet pipe. Two biodigesters stopped running due to the introduction of large size kitchen waste into the mixing tank, while other three bio-latrines broke down due to the introduction of polythene and pieces of cloth materials inside the digester.

Moreover, in some digesters described in the Kenyan case study the blockage of the piping system was caused by the presence of condensed water within the pipe. The only solution is the installation of a simple water trap, that consists of an empty bottle with the function of draining the water condensed from the pipeline at a sloping angle.

It is obvious that the direct consequence of this type of issue is the drop in biogas production. Without inlet feedstock, the digester stops running due to the death of the pathogens within the system that actively operate in the anaerobic digestion process. According to Wamwea [128], the inlet pipe should be designed in a way that a straight rod can be inserted without big effort to stir the feedstock in the inlet pipe or the slurry inside the digester in case of clogging. Therefore, for proper maintenance of the inlet pipe, it is necessary an efficient stirring and filtering system in the plant with a sufficient amount of water available to dilute the feedstock at the entrance of the digester.

The case study literature does not provide enough information about the internal management issues and how they influence the performance of the biogas plants. Though, even if there is not that much evidence, it is possible to give an explanation through the indirect evidence noticed in the case study description. For this specific issue, the lack of motivation or professional attitude among workers can represent the main problem in terms of internal management because little safety measures if they are effectively adopted by the workers, can easily avoid the blockage of the inlet pipe in a biogas plant. They don't request a huge amount of extra work either, 10-20 minutes per day can be enough in order to collect the water, mix it with the feedstock, filter the feedstock and feed the digester [128]. This represents a personal opinion due to the lack of evidence in the case studies but also a clear influence of this factor as it is described in the literature research.

Water quantity

The water shortage is a serious problem that all biogas companies should take into consideration the good performance and the success of biogas projects, especially in rural areas where water availability is limited. According to Bansal et al. [7], a survey conducted in Ethiopia showed that 60% of the total biogas plants (around 700 plants) were non-operational due to lack of water or feedstock. The reason is the high TS content of the feedstock used to feed the digester that requires additional water supply for the optimal digestion process. Usually, the availability of water to dilute the fresh manure is recommended by the biogas companies to run optimally the biogas plants, with an amount that depends on the type of feedstock and the type of digester. However, during the selection of the biogas users, the biogas providers used to underestimate the energy effort that the caretakers should spend for the water collection [34]. Where the water source is way far from the biogas plant, the water collection can be problematic and can be an indirect cause of health and social issues. In Ghanaian and Ethiopian case studies, this problem has been highlighted.

The regions of Dessie and Amhara (Ethiopia) have seen a severe drought in 1998 that forced the farmers to sell all of their cattle and to abandoned their biogas plants. In the Gambaga community (Ghana), where women were in charge of collecting water for the community, the large distance between the biodigester and the water source was one of the issues that led to the not operating of their biogas plant. The women, as water collector, were reluctant to spend more time and energy to collect the extra water requested for the biogas production because more water they have to collect, the less time they can spend for other activities, such as taking care of the children and the house.

With a partial or total absence of water, the anaerobic digestion cannot continue to work. In order to achieve the optimum biogas digester performance, a sufficient amount of water is necessary together with the amount of feedstock. Typically, a 1:1 ratio of water to fresh dung is recommended to maintain a constant performance of the biodigester but this ratio can change depending on the moisture content of the feedstock. As it is explained in the literature research, blockage of the inlet pipe and scum formation can be generated also by a scarce water addition to the feedstock.

Taking into consideration the indirect information given by the case study descriptions about the internal management of the biogas plants, a possible explanation is developed about this specific problem. An evident mismatch between the biogas design developed by the construction companies and the actual biogas users resources is observed. Despite the recommendations and the guideline given by the biogas companies about the water that should be added to the digester, the underestimation of the water collection activity is a clear sign of disagreement with the users' needs.

The poor internal management of the biogas plant can represent an indirect reason for the scarce water quantity adopted for biogas production. Some surveyed biogas plants in Ghana showed the problem of the collection of water by women. These plants were characterised by a hierarchical management structure, where the owner, which in these cases was the head of the family, delegated the hard tasks for the operation of the biogas plant to his workers and the women of the family. Women were in charge of collecting water for the community, and they needed to make an extra round of collection for the water demand of the digester. Skeletal injuries and water-based diseases could be caused by carrying heavy buckets of water over long distances for women [7]. For these reasons, they were reluctant to spend more time and energy to collect the extra water requested for the biogas production. In traditional societies, where the status is obtained by the position covered, the person that performs the highest status position in the group has to make decisions without doing hard work due to the power distance between different status levels. The motivation of them was also constrained by a lack of open dialogue and mutual respect.

Proper time management, in this case, could also be fundamental, especially where long distance and a long period of time have to be spent to collect water. On average, a woman in SSA spends around 40 billion hours every year for collecting water [132]. Eshete et al. in their research suggested an optimal time demand for the collection of water, to run efficiently a biogas plant, of up to 30 minutes [34]. Efficient time management can minimise energy and the time spent on collecting water. However, in SSA entrepreneurship culture there are different "time wasters" due to lack of managerial knowledge such as scarce planning, paying attention to many things at some time, overlooking or underestimating deadlines, counterproductive meetings, restrained communication due to solid power-distance relationships and not planned deadlines for the job tasks [115].

Biogas appliances corrosion

In the case studies previously analysed the fault frequency of biogas appliances corrosion is relatively high (23/121) because of poor maintenance of the several components such as gas tap, air injection ring, air injection hole, and flame pedestal. The air required to combust 1 litre of biogas is around 6 litres (assuming 60% of methane concentration of biogas) and a malfunctioning of the injection hole can affect negatively the flow rate of the biogas consumed [25]. In Ethiopia, the presence of many biogas stoves broken was due to heavy corrosion of the air injection hole and a low pressure of the biogas produced by the floating drum plants. Moreover, most of the biogas lamps installed in the rural area were not-functioning or in a very terrible status, since most of them were kerosene pressure lamps adapted for biogas with the drawback of a very fragile nature (requested weekly or monthly replace). It was observed that the interest of the biogas lamp users was dropped as soon as the lamps stopped functioning. The Tanzanian case study showed that all of the small-scale biogas plants were designed to produce enough biogas to cook for 45 minutes. That represented 1/3 of the total cooking daily time spent by an average household of 5 members. For this reason, some households did not have so much interest in maintaining properly the biogas appliances due to the large availability of charcoal as burning fuel.

Biogas stoves corrosion and broken biogas lamp are just the direct consequences of a poor maintenance and cleaning activity of the several components. The presence of hydrogen sulphide and water vapour in the biogas can generate sulphuric acids that are strongly corrosive, especially for metal materials. As a result, the number of biogas plants that don't consume the biogas increases with social and environmental issues. More than 90% of the total gas leakage issues occurred in the Ghanaian case study is due to the no-application of the biogas produced that is released freely into the atmosphere by the caretakers. This is caused by several factors, such as financial, since farmers or institutions cannot afford the purchase of biogas appliances, technical, since users prefer to avoid technical problems for the use of biogas adopting traditional fuels, and knowledge, due to the lack of on-site training on the construction, operation, maintenance, and servicing of biogas generating systems.

Generally, these type of operational issues is generated also by a lack of awareness of biogas technology. The lack of a proper cleaning system in the biogas plants is an indirect consequence of an inadequate promotion of the technology. With successful cooperation of government, NGOs and the private sector, the awareness of biogas technology can be spread among local farmers, community, and potential other biogas users. In this way, the potential owner can easily understand the importance of each small activity to reach a constant optimal performance of their biogas plants, such as the feeding, stirring, cleaning of the biogas appliances, etc.

Moreover, a proper internal management of the workforce can be crucial for a good maintenance of the biogas plant, since the lack of motivation or professional attitude among workers can represent a crucial limitation for a good execution of these type of activities as it is explained in the paragraph of the 'blockage on the inlet pipe'.

Lack of interest of local users

The lack of interest of local users of biogas plants can be derived from infinite factors. In this part of the evaluation, the only reasons described in the case studies will be taken into account. The lack of interest described in the Ghanaian case study is attributed by the lack of willingness to spend extra money to fix some problems of the biodigesters. They didn't have sufficient technical knowledge to repair the problem by themselves, and at the same time, they failed to reach the construction company for a maintenance service. According to the biogas users, the service companies didn't provide sufficient information on the technical aspects of a biodigester to the local users, and they didn't provide any follow-up service for the maintenance of the plant either. For this reason, most of the owners, as soon as they encountered an issue of the biodigesters, were unwilling to repair it since they did not want to spend more money and time. This aspect can be represented as a lack of initiative from the biogas users that are not willing or not able to find alternatives to overcome biogas adoption limitations.

In the Ethiopian case study, few biogas plants that were not working at the time of visit demonstrated that the owners of the biogas plants lost their interest in operating the plant, but the reasons were not clear. The author argued that the insufficient biogas production that was coming from those plants was one of the reasons since the expectations of the users were disappointed. The design volume of the visited biogas plants was too large compared to the amount of available dung of the biogas users, with design dimensions that were 3/4 even 5 times bigger than the actual sufficient volume based on the available feedstock. Moreover, the amount of biogas generated by the plants was not enough to cover the entire households gas demand, since the biogas users could cook and illuminate up to 3 hours with their own biogas (at maximum efficiency). This aspect led the households to lose their interest in keeping their biogas plants in good working conditions since they used to judge their technology only on its capability to produce enough biogas to substitute

completely the conventional cooking fuels.
Another reason reported is the large distance between the water source and the biodigester that made the women, in charge of collecting water, unwilling to spend more time on it. Finally, the total absence of technical follow-up services by the biogas companies affected negatively the interest of the users to fix operating issues, since they struggled to receive any technical advice and assistance from them.

It is possible to give an explanation about the dynamics behind this issue relying on the indirect evidence and indicators in the case study descriptions that are influential for the biogas plants' performance, as it is possible to notice in the literature research. The lack of interest from local biogas users is mainly caused by partial or total absence of assistance and communication with the biogas service providers. This can be explained by the presence of vertical networks in the SSA society. In the vertical networks, building relationships based on cooperation and open trust between members of different groups is very difficult and it requires money and time investments [47]. The lack of anonymous trust broadens the distance between customers and suppliers, or users and biogas companies because trust and responsibility are always limited to the family or to the vertical network [52]. As a result, as soon as the installation of biodigester is completed and the construction company received the payment from the users or the government, some of them stopped to cooperate with the local people without providing them with any follow-up service or training.

Poor stirring system

In the Kenyan case study, many of failures of biogas plants were caused by the lack of regular stirring. This issue was caused mainly by two reasons that can be interconnected each other: lack of knowledge of the users and lack of interest of the latter. The lack of specialists in biogas technology among biogas service providers has been explained as one of the reasons for malfunctioning. However, the maintenance of the plant is mostly affected by the level of technical education of the owner and the user of the technology. Good maintenance of the biogas plant requires first a good knowledge of the technology which has to be diffused from the top (government, institutions and NGOs) to the local communities. Around 25% of the surveyed biogas users of the case study in Kenya given as reasons for the failures of their plants the lack of knowledge that led a poor or totally absent management of their biodigester. The Ghanaian case study also demonstrated that the lack of a proper practical manual that could describe in detail which activities requires a small-scale biodigester in order to have a good performance.
In addition, the lack of interest is considered another factor for the lack of a stirring system. This factor can be easily related to the lack of knowledge because both of them have as a consequence the poor maintenance of the plant. In the previous section, the connection between these two factors is explained. In the Ethiopian case study, few biogas plants that were not working at the time of visit demonstrated that the owners of the biogas plants lost their interest in operating the plant, but the reasons were not clear. The author assumed that the insufficient biogas production that was coming from those plants was one of the reasons since the expectations of the users were disappointed. Another factor was the total absence of technical follow-up services by the biogas companies affected negatively the interest of the users to fix operating issues since they struggled to receive any technical advice

and assistance from them.

The biogas production is affected by this type of issue in two ways. First, the formation of scum can be generated by the lack of regular stirring of the slurry to remove floccules and to improve the digestion of the slurry inside the digester, as it is demonstrated in the Kenyan case study. Secondly, the blockage of the inlet pipe is also affected by the lack of a mixing system at the inlet, since the daily stirring of the feedstock enhances both the dilution of the feedstock with water and the introduction inside the digester.

Feedstock quantity

Findings of the case study analysis shown that the feedstock availability issue was not so frequent among biogas users. Around 14 out of 121 surveyed people (12%) involved with malfunctioning biogas plants responded to this factor as a big challenge for the success of a biogas plant specifically in certain areas of SSA. Even if the percentage is relatively low compared with the other issues, it is necessary to consider that all the interviews have been collected and analysed based on the comments of local users. Most of the interviewed people didn't have enough knowledge and a sufficient monitor system in order to say if the feeding activity was constant and sufficient for the well functioning of the digester.

A possible cause of this issue is the cattle holding style as it is described in the Ethiopian case study. In some cases, the current practice of cattle roaming on communal grazing fields outside the cropping season represents a limit for the amount of manure available for the biogas plant. In addition, a not correct feeding of the cattle can be considered as a factor for the dung availability. Based on the findings of this case study, the farmers were argued that the amount of biogas obtained from the daily amount of dung was not enough for the domestic energy demand of the household. This can be used as a possible motivation for loss of interest.

Another factor highlighted by the case study of Ghana is the collecting dung system. Some farmers complained about the large distance between the location where the dung is collected and the digester. The energy spent by the workers to collect the feedstock was higher than the one obtained from the biogas consumption. In addition, the availability of cheap firewood made the farmers willing to pay less for this type of fuel instead of paying a higher cost for the collection of dung with a less energy yield.

The obvious consequence generated is a breakdown of the biogas plant. Without feedstock, the digestion cannot take place and as it is described by the case studies the local users are hardly willing to invest in the improvement of the collection techniques and of the cattle holding style.

Due to a lack of substantial information from the case study analysis about the internal management issues that affect the performance of the biogas plants, a possible explanation was developed based on indirect evidence observed in the case study descriptions. Poor internal management can represent an indirect reason for the scarce feedstock quantity adopted for biogas production. Some surveyed biogas plants in Ethiopia showed the problem of the collection of cattle dung. These plants were characterised by a traditional management system, where the workers don't take any initiative due to the lack of technical knowledge on this technology and their fear to fail. This can be derived from the cattle holding style of the workers that limited the dung production but no one was able to give a personal opinion or a solution to this problem because probably they did not have the courage to take an unauthorised decision and to go out from the comfort zone. The lack of alternative collection techniques for the manure is a clear aspect of the lack of initiative. In addition, some cattle seemed to be underfed, which can be connected to not appropriate time management of the workers. Synchronic time management is characterised by several parallel activities handled by the workers at the same time, with the result of not efficient and effective management of the different tasks. This aspect is clearly demonstrated from the description of one of the biogas plants in the case study, that argued the lack of a record system by the owner. It is evident that efficient time management can minimise the energy and the time spent on collecting water.

Lack of training program

This issue, even if it was argued relatively few times from the interviewed in the case studies (12 out of 121), plays a crucial role in the dissemination and the good performance of the small-scale biogas plants in SSA. In the Tanzanian case study, one of the three main factors for the poor functioning of the biogas plants was the lack of proper instruction from the biogas company, which led to a low understanding of the technology from the biogas user and so to the several operational issues mentioned in the previous paragraphs. Moreover, the author of the case study in Tanzania affirmed that even the diffusion of the practical manual, in which answers and instruction can be consulted in case of questions or minor issues, can be considered as instruction training. In Kenya, the interviewed biogas users raised the issue of lack of adequate training by the biogas service providers on how to operate and maintain their biodigesters. In addition, the lack of an operational manual increased the disapproval of the customers, which rather received instructions from the construction technicians on spot. Several interviewees argued that the biogas providers denied on purpose to provide training to users in order to keep the job security in terms of maintenance and the monopoly for repair the biogas system.

The main consequence of this problem is certainly the poor maintenance of the biogas plant. This aspect can be analysed deeply in terms of synchronic time management, lack of initiative (traditionalism) and lack of anonymous trust. The first aspect is demonstrated by the total absence of record system in the Ghana and Ethiopia case study and by the planning method of some owners in Kenya that used to plan the daily activities by their head, without writing them down on a board or a piece of paper. Traditional management is observed by the case studies in Tanzania, where the superior took decisions for the workers and, even if he was listening to the ideas of the workers, a lack of initiatives from the latter is evident due to a low level of knowledge and a lack of communication. The anonymous trust is the last direct consequence among the biogas users that lost their interest and confidence in the availability of the biogas service providers.

The government plays a crucial role in the promotion of training sessions along with the countries. In Ghana, the development of a national biogas programme is necessary, as argued by Bensah [8], in order to support biogas training and microfinance projects targeted at certain communities, households, institutional places or local farmers with high potentials to adopt biogas technology. Therefore, the development of a national biogas promotion body can be the solution for the promotion of specific programmes. In Ethiopia, most of the visited installations were constructed by national or regional (non-local) organizations. The users complained about these organisations that after the installation of the biogas plant typically left the plant without giving any operational and maintenance instructions or training.

Lack of knowledge

All the case studies mentioned this problem in their general analysis as the main factor for the failure of a biogas plant. In the Tanzanian case study, the lack of knowledge of the users was caused by the lack of adequate information by the biogas service, which led to a low understanding of the operation and maintenance of the biodigesters. In addition, the lack of training by the company made the users not able to recognise the failures of their systems, so to fix them. In Ghana, the main reason for the poor maintenance of the majority of the small-scale biodigesters was represented by the lack of skilled caretakers of the biogas plants in Ghana. The lack of knowledge among the biogas users was caused by a low education level of the workers and by insufficient training from the biogas companies. Only 3 biogas plants (located in Anglogold Ashanti Limited) out of 50 were daily maintained by trained technicians that ensured a constant operation of the plants. The survey revealed that most of the biogas plants used for treating human excreta broke down due to the lack of basic knowledge of the components and functions of the technology by the caretakers. Due to the low diffusion of the biogas technology in the case study of Ethiopia, the local communities were not aware of the benefits and the limitations that characterise a biogas plant.

The direct consequence of the lack of knowledge is mainly poor maintenance of the biogas plant, that leads in few years to the complete breakdown of the system if it doesn't receive any maintenance service from the biogas companies. In addition, a profound lack of interest or reluctance among local communities, which can be potential biogas users, about the adoption of the biogas technology is directly affected by this factor, due to an inability to maintain alone the biogas plant and the lack of cooperation with biogas companies. From the case study, it was possible to observe that the lack of knowledge was mainly caused by a lack of training programmes from the government and institutions at a national level. In Ghana, the lack of a national biogas programme is the main reason for the lack of biogas knowledge among local farmers, while in Ethiopia, despite higher participation of national and regional organisations, the biogas users complained a lack of cooperation and communication with biogas providers after the installation of the biodigesters.

In the case study descriptions, this issue was considered by the majority of the authors one of the most influential in the performance of the small-scale biogas plant analysed. However, during their interviews, a few biogas owners mentioned their lack of knowledge as the main issue for the failure of their biogas plants (7 of 121). This is an indicator that the findings of the interviews, especially the one obtained from the literature, should not just be taken at face value, but has to be analysed into the cultural values and institutions behind it.

Figure 4.20 shows an overview of the causes and consequences of the issues analysed in the previous section derived by the evaluation.

Issue	Cause	Consequence
Lack of follow-up service	• Lack of written agreement with the owner by the biogas company • Lack of communication between owner and biogas company	• Poor maintenance of the biogas plant • Breakdown of the biodigester • Lack of interest of the owner to fix the problems
Gas leakage	• Poor quality of the plant structure • No-use of biogas produced • Lack of maintenance of the gasholder • Age of the plant • Poor quality material for the construction	• Decrease biogas production • Health hazard for household • Environmental issue
Blockage of the inlet pipe	• Lack of filtering system • Lack of cutting and diluting system • Condensed water within the pipe • Poor maintenance	• Decrease of biogas production
No water availability	• Extreme weather condition • Long distance from the water source • Lack of alternative water collection techniques	• Not complete digestion of substrate • Scum formation • Blockage of inlet pipe • Abandoned biogas plant
Biogas appliances corrosion	• Poor maintenance • Lack of cleaning system of the components • Pressure biogas too low • Lack of interest • High-water vapour content of biogas	• Biogas not consumed by the owner • Gas leakage • Use of fossil fuels for cooking and lighting
Lack of interest of local users	• Lack of willing to spend extra money for maintenance • Lack of technical knowledge • Lack of follow-up and training service from biogas companies • Insufficient biogas production • Large distance from the water source	• Poor maintenance • Abandoned biogas plant
Poor stirring system	• Lack of knowledge of the users • Lack of interest of the users • Lack of follow-up service	• Scum formation • Blockage of inlet pipe • Decrease biogas production
No feedstock availability	• Animal holding style • Large distance from dung location • Extreme weather condition	• Not enough biogas production • Loss of interest • Breakdown biogas plant
Lack of training programmes	• Lack of support from government or NGOs	• Operational issues • Lack of knowledge • Lack of interest • Synchronic time management • Lack of initiative
Lack of knowledge	• Lack of training programmes • Lack of instructions from biogas service providers	• Operational issues • Lack of interest • Synchronic time management • Lack of initiative

Figure 4.20: Overview causes and consequences of the case study issues

4.3. Evaluation Assessment

The previous chapter demonstrated the most frequently occurred issues that are commonly experienced by owners of small-scale biogas plants in Sub-Saharan Africa. What becomes clearly visible is that a small amount of specific data about the internal management and the business environment has been found, due to the fact that the authors of the case study descriptions could not define these two areas as direct causes of the operational and technical issues experienced by the biogas plants. However, there are reasons to suspect that they play an essential role in the generation of the operational issues previously mentioned, since proper maintenance of biogas plants is achieved by people that need to be managed properly by the owner and they need a good business environment in order to be able to operate. In addition, proper maintenance of the biogas plant is the result of a good knowledge of the technology, which is a direct consequence of the activity succeeded by the cooperation of the government, the NGOs and the private sector, in terms of communication, training sessions, and technology promotion.

The case study analysis showed that lack of follow-up service is the most occurred issue in the small-scale biogas plants, reflecting poor cooperation between the biogas providers and the users. Biogas owners need to interact with the biogas providers, which sometimes don't provide an after-sales service after the installation of the digester as a result of the presence of vertical networks in the socio-cultural environment operating in SSA. This aspect can generate a lack of interest among biogas users to fix the malfunction of the proper digester, due to a lack of knowledge and a lack of external technical support. For this reason, an additional value, called "cooperation between providers and users", is introduced in the "Business environment" cultural aspect. This value describes to what extent technical support from the installation company may be provided in order to make the biogas users able to operate and maintain properly their biogas plants.

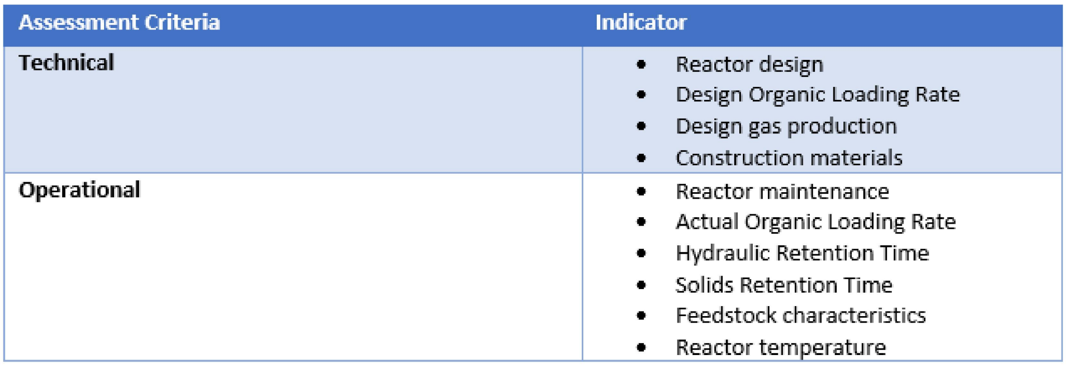
The technical issues observed through the issues evaluated in the previous paragraph are linked with all the technical indicators present in the assessment criteria table developed in the literature research. Gas leakage represents the second most occurred issue and it is mainly influenced by a poor reactor design. The installation of the gas pipe requires gas-tight joints, protection of the pipe from the irradiance and the mechanical hits and dried pipeline. Moreover, a proper mechanical stirring is necessary in order to avoid agitation issues that are going to cause other operational issues, such as blockage of the inlet pipe.

The majority of the biogas plants in the case studies were affected by operational issues, including the blockage of the inlet pipe, water quantity, biogas appliances corrosion, and the feedstock quantity. In terms of operational parameters, the reactor maintenance is considered one of the most important, since the corrosion and the blockage can be overwhelmed with a proper gas cleaning and a frequent daily agitation of the feedstock in the inlet pipe. In addition, a proper actual OLR regulates the amount of water and feedstock introduced in the digester every day and fluctuation of these two factors can affect negatively the biogas production. The reactor temperature was not monitored in the plants due to a lack of proper equipment and a lack of awareness about the importance of this parameter for the control of the anaerobic digestion. Moreover, local biogas owners didn't pay too much attention since even in winter the temperature doesn't decrease so drastically.

By analysing individually the case studies with the support of the literature, the role of the government is fundamental first for the promotion of the biogas technology, through practical demonstrations, financial supports, policy framework, and the cooperation with all the stakeholders involved in the biogas business. In addition, it plays a key role for the share of knowledge among local biogas users through the so-called "Social Innovation Events", in collaboration with local NGOs and biogas companies, since the lack of knowledge and the lack of interest are then principal causes for the appearance of operational issues such as a discontinuous feeding, a not efficient stirring, filtering and cleaning system, and an inappropriate water/dung ratio. The internal management of the workforce is also affected by the lack of knowledge because workers are not confident to take initiatives or share individual opinions, and the owners are not willing to organise the several activities with an optimal planning time management. All these aspects lead to enhance hierarchical management, where high-power distance, closed in-group mentality, lack of discussion, and particularistic relationships are present.

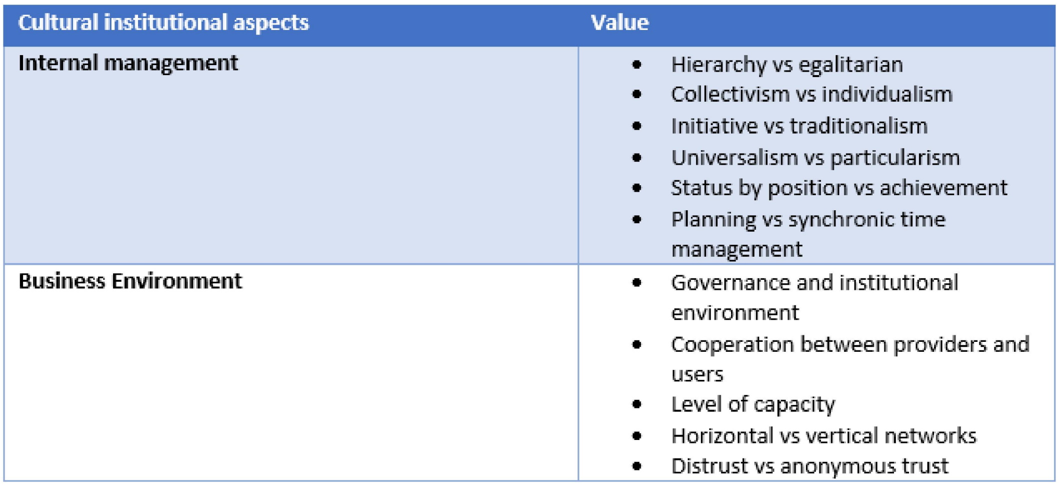
As a result, a new value in the 'Business environment' area of the cultural institutional aspects is introduced, called "Level of capacity", which should reflect the education, in terms of not only technical knowledge and skills but also professional mindset and attitude, presented among the biogas owners. The biogas technology is not so complex to requires a highly qualified personnel, it requires a basic knowledge of the technology, such as the anaerobic digestion, the optimal feeding system (manure and water), the optimal management of the inlet and the outlet slurry (in terms of stirring, filtering), and a proper use and maintenance of the biogas appliances, in order to keep the biogas plants running properly for years. Moreover, also the fixing activity of technical issues, such as gas leakage, biogas stoves corrosion, piping damaged, presented in the plant requires less than half-day of work of a skilled expert and small investment, as it is described in the Ethiopian case study. However, poor internal management characterised by synchronic time management, traditionalism, particularism and hierarchy, that affects the professional attitude of the workers and their motivation to be efficient, can be crucial even for achieving small tasks. In the Kenyan case study, the author affirmed that most of the operating biogas plants were just following proper guidelines given by the biogas providers. In addition, more egalitarian workforce management induced to a more professional approach of the workers on the several activities planned by the owner.

Following these findings, an evaluation assessment for the evaluation of the performance of a small-scale biogas plant in the Sub-Saharan African context can be developed, which is composed by the two tables described in figure 4.21 and 4.22.



Assessment Criteria	Indicator
Technical	• Reactor design • Design Organic Loading Rate • Design gas production • Construction materials
Operational	• Reactor maintenance • Actual Organic Loading Rate • Hydraulic Retention Time • Solids Retention Time • Feedstock characteristics • Reactor temperature

Figure 4.21: Technical and operational indicators for the performance characterisation of a small-scale biogas plant



Cultural institutional aspects	Value
Internal management	• Hierarchy vs egalitarian • Collectivism vs individualism • Initiative vs traditionalism • Universalism vs particularism • Status by position vs achievement • Planning vs synchronic time management
Business Environment	• Governance and institutional environment • Cooperation between providers and users • Level of capacity • Horizontal vs vertical networks • Distrust vs anonymous trust

Figure 4.22: Cultural institutional values as preconditions for the performance of a small-scale biogas plant

It is important to mention that more research is required to improve the analysis of the performance of small-scale biodigesters, especially on the parts of the evaluation assessment that are not developed enough. Special attention should be given to the direct connection between internal management and operational performance of the biogas plant.

5

Recommendations

The previous chapter provided a thorough analysis of the general performance of small-scale biogas plants in SSA and their most frequently occurred issues that limited their efficiency. The analysis was realised through the use of the evaluation framework developed in the third chapter and the latter was consequently validated by the case studies observing which parameters returned in the analysis. This chapter discusses the case study analysis and the issues evaluation, indicating the main recommendations to deal with the issues analysed in light of the evaluation assessment developed.

5.1. Cooperation between biogas providers and users

A proper after-sales service strategy should be developed. In the installation contract of the biogas systems, the follow-up service should be included:

- Demonstration and training session of the several feeding activities (feedstock collection, water collection, dilution, mixing, condense water removal, desulphurisation if necessary, utilisation of the biogas, utilisation of the bio-slurry), record system for the activities with the provision of a contact to be called in case of questions or issues. The biogas users need to be able to recognise possible issues in case of limited biogas production, and if these issues are minor they should be able to fix them as well thanks to the training received by the service providers.
- Regular check-up on the biogas plants performance and conduction of interview with the biogas users about experiences and issues.

The regular check-up should be made possible during the feeding period in order to give the possibility to the service provider to observe the several activities and give practical recommendations on that. In addition, if the plant has some biogas appliances corroded, a sample of the biogas produced can be taken and analysed in the laboratory in order to check the composition of the gas and the level of H_2S and H_2O. In case of mixed feedstock, such as food waste or different type of substrate, a sample of it should also be taken and analysed to see the biogas potential and the several parameters (pH, VS, and TKN).

5.2. Installation planning complied with the users' capacity

The aim of installing a biogas plant can vary from waste management and environmental security to energy production and improve living conditions, but it must firstly comply with the end biogas users' needs and their resources.

The first step of a concrete planning installation process is to answer the following questions:

- What is the scope of the biogas project?
- What is the needs and expectation of the potential biogas users?
- How can continuous and regular supply of feedstock be guaranteed?
- Where can the biogas plant be situated?

The crucial points for the realisation of a biogas project are the availability of the feedstock supply and the feasibility of selling or using the biogas produced. Furthermore, it is important to ensure if the biogas plant can run successfully in local conditions.

The first step for the development of a biogas project is to make an honest inventory of the available type and quantity of feedstock in the plant location. Crucial characteristics of the feedstock to be evaluated are CH_4 potential, biodegradability, composition, and the water content, as well as the costs in terms of transportation and collection. In addition, the daily potential amount of feedstock available and the size of the biogas plant design should be connected during the development of the project. From the case study analysis, it results that many biogas users lost their interest in maintaining their biogas plants due to a mismatch between the installed digester capacity and/or the locally available feedstock and the user' need. As a result, the biogas produced is just flared or even worst released in the atmosphere causing air pollution. This aspect represents a serious problem that needs further research since the first aim of the biogas companies should be to satisfy the user' needs.
The supply costs of the specific feedstock, in terms of the amount of energy and money that should be spent for the collection and transportation to the plant, must always be counted in the evaluation of the project's feasibility. If the solid content of the feedstock exceeds the optimal limit and additional water is requested for the AD process, the feasibility assessment of the project should also include the supply costs of the water.

The next planning step is the evaluation of the site for the construction of the plant. Some important considerations can be established to guarantee the suitability of the location:

- The location of the biogas plant should be at a proper distance to avoid health risks and unpleasant odours in case of malfunctioning.
- The site should be located as close as possible to the user's household to avoid gas leakages and excessive investment for the use of more construction materials.
- The soil of the site should be evaluated before the starting of the construction step.

- The plant should be located nearness the feedstock production site to minimise energy, time and money costs for transportation.

The location for a biogas plat cannot be decided easily but it requires precise calculations that take into account also the end-users' needs and expectations from the technology.

5.3. Suitable installation of the biogas plant

The most important aspect that necessitates attention before the construction of the plant is the size of the digester and gasholder. Some systems in Tanzania had important biogas losses (around 22%) through the rim between the digester and the gasholder do to a volume mismatch. A better fit between these two components should be considered to reduce the biogas losses to the open air. The author of the Tanzanian case study suggested two types of biogas system that could reduce the biogas losses to around 14%, which are the SIMTANK and the AFRITANK systems.
In addition, the solid tape is suggested as repairing material to be able to change a separated failing part instead of replacing the entire gasholder. To minimise the risk of the blockage of the inlet pipe, construction companies should design it as much straight as possible, with a diameter large enough to allow the introduction of the feedstock available on site (10-15 cm for liquid substrate and 20-30 cm for more solid feedstock). In this way, even if a possible blockage occurs, the pipe is accessible to be cleaned with a rod or a pole. In the case study of Tanzania, it is recommended to install a 2"-ball valve to the T-connector at the lower extreme of the inlet pipe. Most of the plants in the case studies struggled with weekly blockage of the gas pipe as well due to the presence of condensed water in the tube. This frequent issue can be easily avoided through the installation of a water trap at the lowest point of the biogas pipe, and the end of the pipe must be uniform as well, otherwise, the water might condense and collect at some cavities along the pipe. Moreover, the pipe should have a slope of minimum 1% and should not be more than 30 cm underground to avoid water cooling.
Desulphurisation of the biogas can be required in case of frequent corrosion of the biogas appliances, and the absorption technologies are suggested in case of a small-scale biodigester for their low cost and relatively high efficiency.
Also, the material adopted for the construction of the biodigester is crucial for the quality of the entire plant and its biogas yield, even with excellent workmanship. The most used materials for fixed dome digesters are cement, sand, gravel, water, bricks and stones. It is important that the sand used for the construction should be clean for plastering work since every impurity can lower the strength of the structure. The gravel should not be bigger than 25% of the thickness of the concrete product that is used with [73]. Water is mainly used for preparing the mortar for either masonry or concreting construction and plastering. The cleanliness of the water, as well as for the sand, is crucial for the final strength of the digester, therefore water from ponds or canals should not be used. Bricks are highly recommended if they are locally available for their low cost, but they required a proper preparation, including the drying and the shaping activity. For the construction of balloon gasholders, glass-fibre reinforced plastic (GRP) is the most suitable, since it has a good gas tightness and corrosion resistance, and it is not difficult to repair. In order to avoid deterio-

ration issues for plastic gasholders, a sort of roof or the application of a UV-resistant coating should be installed to avoid the deterioration for direct irradiance. It is important to mention that in presence of these types of material locally, the construction companies should always prioritise the adoption of them in order to promote the sustainability of the project and improve the local business environment, but they must also consider the quality of these materials to avoid future structural issues and to guarantee the optimal performance of the plant.

5.4. Optimisation of water quantity

In all case studies, the feedstock supplied to the biogas plants requires the addition of water due to its high TS content. This aspect should play a fundamental role during the planning installation phase of the biogas companies that should consider firstly the availability and the characteristics of the feedstock presented in the plant site. In the SSA region, especially in Ghana and Ethiopia, the water shortage is considered a serious problem for the performance of the biogas systems. Therefore, the time and the energy required to supply the water demanded to the biogas plants should be optimised. According to Bansal et al. [7], the average amount of water required for an optimal feedstock mixing is 50 litres per day for each cow or 10 litres per day for each pig that provides manure for the digestion process. For many biogas users, without access to transport for the collection of water, spending energy and time to collect additional water to run the digester is not that attractive, especially when extreme climate conditions limit the domestic water supply. Greywater from the kitchen and the toilets can be recycled as a diluting agent or the rainwater can be harvested in tanks and used as water supply. The latter method was adopted by the Nepal Biogas Sector Partnership (BSP), with the adoption of 2-6 m^3 tanks for rural farmers, and in Burkina Faso as well [73]. Households roofs can be implemented to collect water with the use of polyethene sheeting or plastic cover on all the roof to increase the harvesting area. If rainwater harvesting with the use of the roof is not sufficient, open pound or ground catchment should be used.

As it is demonstrated in the Ethiopia case study, water collection can be very time demanding. Therefore, before the construction of the biogas plant, it is important to understand the several activities that the potential customer used to accomplish and the potential impact that additional activities such as water collection could make. In addition, an education programme should be included alongside the construction of the biogas plant to teach the biogas users an efficient water collection method and proper time management of the several activities.

5.5. Appropriate maintenance of the plant

A proper daily, weekly or even annually maintenance of the biogas plant requires firstly, the interest of the biogas users to keep the system in optimal conditions, and secondly, a good level of discipline and routine for the several operations required to ensure a long life-span of the biogas plant. From the case study analysis it was possible to observe that poor maintenance of the plant was mainly caused by negligence or superficiality of the workers. A

less complicated or standardised design, that is convenient for the type of feedstock, the climatic conditions, the work routine and the technical knowledge of the user, should be considered. In addition, proper training for biogas users and workers should be coordinated in order to give the right guidelines to maintain an optimal biogas production and to fix possible minor issues of the system. It is important to take into consideration that biogas users should notice both economically and social benefits, such as time-saving, with the adoption of the biogas system. The latter benefit influences also the resulting maintenance operations that should relieve the owner from work rather than increase its workload.
Daily maintenance operations are directly connected with the performance of the biogas plant and the most important are the following:

- Constant and appropriate feeding of the digester: the available feedstock has to be inserted in the digester as soon as possible in order to avoid pre-digestion. A filtering system (mechanical or manual) should be applied to remove unsuitable materials. The daily quantity of feedstock used should be recorded to control the performance of the plant.
- Agitation: manual stirring method should be adopted to mix properly water with the feedstock collected. If the plant is not provided by a mechanical stirring system, poking the substrate with a stick or a rod through the inlet pipe is recommended. In order to avoid the blockage of the inlet pipe, regular stirring several times per day must occur. Biogas users should be aware of the benefits that this activity brings to the performance of the biogas plant. In this way, they are encouraged to follow the routine.
- Maintenance of the toilets: in case of bio latrines, the toilets don't require heavy maintenance except for keeping clean the inlet tank and the floor of the cubical.
- Maintenance of the biogas appliances: biogas stoves should be kept clean like other kitchen utensils. The cleaning of the glass screen of the biogas lamps is requested only if necessary, to avoid breakdown of the lamps in case of the ruin of the gas mantle. Gas mantles have a limited operating life and must be replaced frequently.
- Checking gas production: identifying a low level of biogas production is fundamental to act immediately on the issue and not compromise the entire system. The cause could be either biological, such as temperature, substrate, pH change, or structural, such as leakage in digester or pipes, blockage of the gas pipe due to water condense.

Weekly and monthly maintenance operations are the most forgotten activities due to a lack of awareness on the impacts that they can generate on the performance of the biogas plant. The main activities are the following:

- Checking of the water trap
- Regenerating of the desulphurisation system if exists
- Stirring the sinking layers of scum in the fixed dome digester
- Accurate cleaning of the floating drum

- Checking of the plastic pipes
- Checking of the slurry storage tank, and emptying them if required

Lastly, every year the biogas users should check the plant in terms of possible corrosion, and if necessary they should replace the protective coating material with a new one. In addition, they should check the piping system in terms of possible gas leakages. If necessary, this type of issue should be identified and repaired immediately.

5.6. Sufficient monitoring system

All the activities mentioned in section 5.5 should be monitored together with the performance of the biodigester performance. The collection of this information has different benefits:

- Provides useful data to the biogas providers for their performance evaluation of the plant
- Aids in detecting problems that ruin the plant's performance
- Provides a base for economic analysis
- Provides a base for the comparison of different design and different method of operation

Monitoring and data record which become crucial for the good performance of the existing biogas plants should be achieved by the plant owner or by a person appointed by him/her. The amount and type of feedstock, including the water quantity added, is the most important information that necessitates daily control. Through the measurement of the substrate temperature, issues in the production of biogas and the digester heating system can be detected. The gas production can be monitored by the gas meter between the digester and the gasholder or between the gasholder and the consumption point, or simply by consumption observation. The biogas owner should also record the occurring issues and their possible causes.

With the cooperation of institutions, associations and companies which can conduct several measurements with the use of more sophisticated instruments, the analysis of the pH-value of the substrate inserted (monthly), the biogas composition (monthly), and the fertilising value of the bio-slurry (annually), should be achieved with the aim to optimise biogas technology as well as to avoid future issues.

5.7. Improve capacity

The term "capacity" concerns not only the practical knowledge and skills for the biogas maintenance but also the attitude and cultural values, including aspects like trust, cooperation and vertical networks, that influence the way to put into practise the technical and operational skills. Practical knowledge, implementation and experience on biogas technology is very limited in SSA as the case study analysis has shown, but also having a professional attitude and managerial skills is fundamental to be able to tackle any barriers that the biogas plants encounter.

With the introduction of the U.N Millennium Development Goals (MDG) in 2000, many SSA countries committed to working to achieve universal primary education. The region has obtained the greatest improvement in this field compared to other areas of the world, with the number of children enrolled in primary schools doubled between 1990 and 2012 to 149 million children [53]. However, the general level of education in SSA is low, because most of the students who attended primary schools struggle to attend secondary education due to the lack of financial support and the long geographical distance from home. In addition, people living in rural areas are more likely to start working after primary school compared to people from the urban area. Only 30% of rural youth have attended school [118].

As mentioned in paragraph 4.2.1, the lack of training is one of the main issues that lead to the poor functioning of most of the biogas plants, since biogas owners and workers were not able to maintain properly the biogas system. Moreover, according to Geers [43], higher educated managers are less hierarchical and their workers receive more responsibilities. In addition, the heavy bureaucracy of the institutional environment can be handled easily by educated entrepreneurs, as well as the management of any supporting method that makes planning, monitoring, maintenance more efficient.

National and regional programmes should invest significantly in training, especially in rural areas, both for biogas providers, to guarantee the necessary dissemination and installation knowledge available locally, and for biogas users, to make them aware about the appropriate operations and maintenance of their biogas plants and about the benefits obtained from the correct application of biogas and bio-slurry. In addition, training programmes and workshop to provide the education for running a biogas business should be promoted for biogas users to operate the biogas plants and their workers efficiently. However, training programs should be adapted to the business environment where the program is located, by including the cultural values and institutions in order to enhance entrepreneurial activity. Usually, training programmes fail to provide the practical capacity to overcome daily issues because they don't take into consideration the local socio-cultural and economic context [64].

Another way to spread the biogas knowledge is through demonstrations of already existing fully operating biogas plants. One of the reasons that led to a lack of interest on repairing malfunctioning biogas plants of their owners, in the case studies analysed, was the presence of a high amount of failing biogas plants around them. The organisation of visit tour in biogas plants that operate optimally can increase the awareness on the proper maintenance of this system and the interest in keeping the biogas plant operating to benefit from that.

Communication regarding biogas should improve to achieve a good knowledge spread. The interactions between local people are considered the most effective way to spread awareness and the installation of biogas plants. In addition, social events organised by local NGOs and biogas companies play an important role for the share of knowledge among biogas users, such as the "Social Innovation Events" mentioned in the South African case study.

5.8. Teamwork

Biogas owners should experiment with developing a mixture of teamwork and remuneration. In traditional biogas plants, paternalism is often identified, as they are characterised by domestic management and a hierarchical head of the family. Teamwork could match with the African socio-cultural values as well since it is characterised by unity and communitarianism, but with a reduced power distance. In terms of internal management, the biogas owners should involve more the employees, allowing them to discuss their personal ideas and leading them to plan properly their activities in order to be more efficient. As a result, the workers may feel valued, and a higher professional attitude, initiative, responsibility and motivation can be induced. This means that a combination of a hierarchical management style with a more egalitarian communication and cooperation should be requested. According to Geers, the adoption of this management style by SMEs in Tanzania contributed to increasing their productivity and performance [43].

In addition, an individual appraisal based on performance should be included in the management method. However, a different attitude amont the workers, and thus extra energy and time consumption, is necessary to establish a more egalitarian internal management. Even a negative remuneration can be considered for negative performance, such as for delays or negligence at work, in terms of small subtraction from the salary or verbal admonitions.

5.9. Development of National Programmes on biogas technology

The government plays a crucial role in the good dissemination of biogas technology, and for the consequent success of the biogas projects in SSA. The national programme should focus on the three main areas involved with biogas: agriculture, sanitation, and energy. These aspects are fundamental for both domestic and institutional biogas plants. Biogas training should be financed by the government and donor agencies, and potential biogas users with low economic capital, such as rural farmers, should be encouraged to adopt this technology with microfinance programmes targeted at these type of social groups.

In addition, the involvement of all the stakeholders in developing successful biogas projects is necessary. NGOs, such as GTZ and SNV, should develop training programmes for professionals involved in the installation of biogas plants, with the collaboration of researches from institutional departments that should work on the development of innovative and efficient digester design.

Since most of the people in SSA are not aware of biogas technology, more attention should be laid on potential biogas users explanation. Moreover, concrete demonstrations of operating biogas plants should be provided to show the several benefits obtained with the use of this technology. Finally, operational guidelines, written and in plain sight preferably, are recommended not only to the biogas owners but particularly to the workers in charge of the daily feeding.

6

Conclusions and reflections

This report began with the introduction, which introduced the research questions described in paragraph 1.5. This chapter will conclude the thesis report by answering the research questions based on the literature research, the case study analysis, and the subsequent recommendations. In addition, a reflection will be provided that discusses some limitations experienced during the research.

6.1. Conclusions

This section presents the conclusions obtained from the research project by answering the research questions described in paragraph 1.5. First, the main research question will be answer, which is composed by the several sub-questions that will be answered successively.

6.1.1. The main research question

This paragraph will answer the main research question, which was presented in paragraph 1.5. The answer is matured and composed by the different sub-questions further described and explained.

What are the causes of the poor performance of a small-scale biodigester in the Sub-Saharan Africa and how can this performance be improved?

The high number of malfunctioning or not operating small-scale biogas plants is a clear alarm that all the stakeholders involved, including the biogas users, for the development of the biogas technology should raise their efforts in order to avoid all the issues that affect negatively the performance of a biogas plant.

In a technical point of view, the installation of the biogas plant is a crucial step that influences the future performance of the biogas system. Gas leakages are very common when the reactor design includes some defects. More than 60% of the gas leakage is generated through the gas pipes that are sensitive to the presence of water and hydrogen sulphide in the biogas that can corrode the metal material. Moreover, the use of local materials can induce the generation of cracks or deterioration of the gasholder (depending on the type of system) if their quality is not appropriate. A proper planning installation step of the biogas plant can reduce the occurrence of technical and operational problems. The aim of the biogas companies should be to comply the user's needs taking into consideration technical factors that are fundamental for an optimal biogas production such as the design OLR, the reactor design, and the construction materials,

The main operational issues that negatively affect the biogas performance are the blockage of the inlet pipes, improper water and feedstock quantity, the corrosion of biogas appliances, and the lack of a proper stirring system. The first problem is the result of an inadequate filtering system that should remove the unwanted materials before entering in the digester, or it can be caused by the presence of an inadequate piping system that doesn't allow free-flowing of the feedstock at the inlet. The irregular feeding with water and manure of the digester is a crucial issue since due to extreme climate conditions, lack of alternative solutions and monitoring system, most of the biogas system stopped running. Poor maintenance of the biogas appliances induces also to the corrosion of these technologies due to the presence of sulphuric acids that react with the metal materials. In this way, even with optimal biogas production, the users would notice a weak flame in their biogas burners and they couldn't cook properly. The last issue causes the formation of scum and the blockage of the pipes that hinder the performance of the biogas plants. A low technical education of biogas users also induces the presence of this issue, since sometimes they are not aware of the importance of a regular and frequent daily agitation activity. An efficient maintenance operation of the biogas plants is necessary to avoid all these operational issues but it requires first the awareness of the biogas owners on the benefits obtained from a good production of biogas, second, a good level of discipline and routine can facilitate the achievements of the periodical activities. In addition, all these activities should be monitored together with the performance of the biodigester performance. The amount of feedstock and water added in the plant is the most important information that necessitates a daily control but also other important parameters such as temperature, gas production, pH value, and agitation and cleaning system.

In the internal management area, most of the biogas owners showed a hierarchical attitude towards their workers, where the decisions were taken by the superior and a paternalism control system was dominating. A lack of communication between workers and owners influences the interest of the first to share personal ideas, opinions and to take initiatives even when they observe some problems. Biogas plants remain to struggle with adequate time management, punctually, planning and controlling, and have a generally fatalistic attitude to combine more activities. This is especially hindering the productiveness of the biogas plants because several operational issues are caused also by the lack of adequate time management. All these aspects are supported by limited practical knowledge and experience on biogas technology of the owners, that struggled to organise all the necessary activities and control the productiveness of their workers. Most of the time negligence of the workers was mentioned as an issue for the productiveness of the biogas plant. For these reasons the teamwork, a mixture of hierarchical management style with a more egalitarian communication and cooperation with the workers is requested. The biogas owners should involve more the employees, allowing them to propose ideas and take initiatives. As a result, the professional attitude and the motivation of the workers can be boosted, leading to an increase in their performance and the general productivity of the biogas plants.

The factors that mainly influence negatively the performance of the biogas plants in terms of business environment are the presence of vertical networks, the lack of follow-up service from the biogas companies, the lack of proper support from the national government, and a poor capacity level. Vertical networks are characterised by limited cooperation and open networks of responsibility among members of different groups, and biogas owners need to invest time to build trust and cooperation with a future partner, such as biogas providers or other suppliers. This aspect is strictly connected with the lack of assistance from the biogas providers to biogas users after the installation of the system, accentuated by a lack of communication between them. In this way, biogas plants cannot receive adequate maintenance as soon as they experience an issue. The users usually don't have sufficient technical knowledge to evaluate any problems, and also they lose interest in spending more money and time to repair the plant. As a result, a profound lack of trust broadens the distance between users and providers, and it supports also the existence of vertical networks. Lastly, the support of the government for the diffusion of the biogas technology, in terms of knowledge spreading and financial operations, is still weak. The lack of knowledge among biogas owners is caused mainly by the lack of training programmes or demonstrations from an institutional organisation, which led to a low understanding of the operation and maintenance of the biodigesters. In addition, the not sufficient service provided by biogas companies to their customers is also induced by a lack of cooperation with the government and a lack of financial support from it. National and regional programmes should invest significantly in training, especially in rural areas where the education level is lower, both for biogas providers and users, to make the latter aware about the appropriate operations and maintenance of their biogas plant. Finally, the involvement of all the stakeholders in developing successful biogas project is necessary to generate horizontal networks based on anonymous trust and open dialogue.

6.1.2. The research sub-questions

The findings of the research conducted in this report related to the sub-questions will be described below.

a) *What are the main technical issues that a small-scale biodigester encounters during its lifetime?*

Through the case study analysis it was possible to observe that gas leakage was the most frequently occurred technical issue that small-scale biogas plants had experienced.

This problem is mainly generated by the poor quality of the reactor design, and it is boosted by a lack of maintenance of the biogas system. In most of the plants affected by gas leakages, the age of the plant played a crucial role due to the fact that longer the biogas plant is running, the more damages or corrosion of the gasholder or the piping system can occur. In Ghana, all the plants with gas leakages had more than 10 years of operation. The adoption of poor materials during the construction of the biogas system is also another cause of this type of problem. It was clear that biogas companies used primarily materials that were locally available due to their low costs. In Ethiopia, several gasholders had cracked due to the adoption of low-quality bricks and concrete that couldn't handle the pressure of the gas. On the other hand, most of the local biogas users were induced to use local materials, even if their awareness about the poor quality, because they couldn't afford the high transport costs for the use of imported material. Another aspect is the design of the system. It was possible to notice that in Tanzania most of the gas leakages occurred through the rim between the gasholder and the digester due to an improper proportion between these two units. In addition, some plastic balloon gasholders in Ghana were also deteriorated due to the lack of protection from the direct solar irradiance and from possible animal damages. All these technical aspects can be easily be fixed by proper maintenance operations of the piping system and the gasholder unit, that required practical knowledge on biogas technology. awareness of biogas technology.

Other technical issues experienced by the biogas plants analysed in the case studies were pH-value changes, too short HRT and organic overload, but they were not evident in the case study description due to the lack of knowledge and monitoring system of biogas owners that were not able to fully understand the causes of the low performance of their biogas plants. However, these aspects were affected by more evident operational issues that will be discussed in the next sub-question.

b) *What are the main operational issues that small-scale biodigester experiences during its lifetime?*

The operational issues were the most occurring in the biogas plants analysed in the case studies. The blockage of the inlet pipes, improper water and feedstock quantity, the corrosion of biogas appliances, and the poor stirring systems were the main operational issues.

The blockage of the inlet pipe is the most occurring issue in the Tanzanian case study due to the presence of oversized or inter materials in the feedstock that should be first removed. In addition, the installation of T-connector at the lower extremity of the pipe did not allow the correct flow of the substrate into the digester and proper mixing with the water.

Water shortage is also a serious problem that affects some biogas plants in SSA, especially in Ghana and Ethiopia, due to extreme climate conditions. As a result, the limited amount of domestic water and the lack of alternative solutions to collect additional water for the biogas system led biogas users to lose their interest in spending extra time and energy to collect more water, especially if women are in charge of this activity because they need to take care of the house and children.

The biogas appliances corrosion was just the result of the lack of a biogas cleaning system that could remove the hydrogen sulphide and the water vapour from the biogas produced because they can react and generate sulphuric acids that are strongly corrosive for metal materials. In addition, the majority of the owners didn't clean regularly the appliances after the utilisation.

In Kenya, a low technical education level of biogas users led to a poor stirring method in their biogas plants. They were not aware of the importance of a regular and frequent daily agitation activity for the performance of the biodigester. The formation of scum and the blockage of the pipes were the direct consequences.

Lastly, the irregular feeding of the digester was considered as the main operational issue. Most of the interviewed people did not have enough knowledge and a sufficient monitoring method to be able to guarantee a constant and sufficient daily feeding activity. The problem was evident in institutional biogas plants where during the summer season, when the schools are closed, the digesters could be fed once every week.

c) *Which internal management behaviours and strategies of local entrepreneurs can be identified in the current SSA context?*

Even though some differences among cases about internal managements methods have been identified regarding the current SSA context, the most evident will be discussed below to answer this sub-question. Many biogas owners showed a hierarchical attitude towards their workers, in which decisions were taken at the top and a paternalism control system prevailed. In the South African case study, very few owners showed a more egalitarian management style but they recognised the necessity of investing extra time and effort in stimulating and motivating the workers to take initiative and to behave more professionally. Status by position is still playing a major role in the biogas business in SSA. The head of the family is always the person that takes the decisions for the rest of the group, even if he doesn't have the sufficient knowledge to know what could be the right decision to take. This influenced the interest of the employees to share personal ideas or opinions about the activities to run a biogas plant.

Due to the frequent synchronic time management in SSA, the majority of biogas plants did not have a record system for the several daily tasks that the employees should accomplish and a poor planning system led to procrastinate some activities to one or few days causing several issues previously mentioned.

d) *How is the business environment in SSA affecting the entrepreneur's activity in the context of the current biogas sector?*

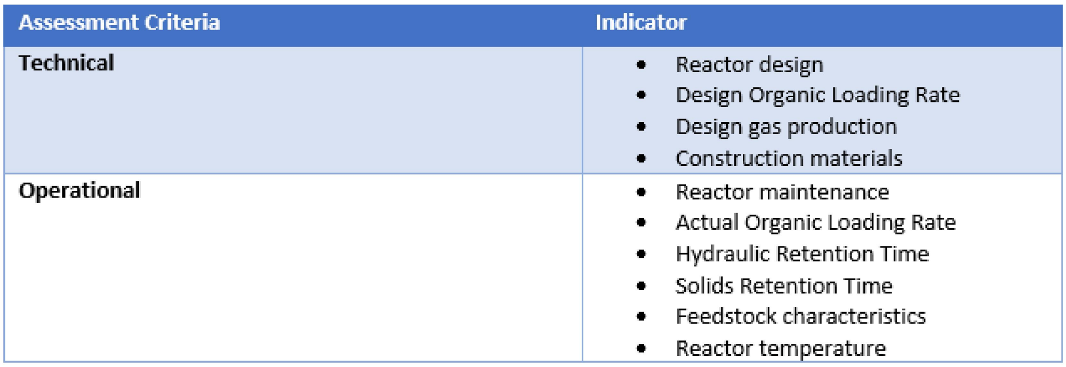
The presence of vertical networks in SSA is still evident, where obtaining some services or licences is still complicated and it can be facilitated by having the right contacts and being inserted by the convenient vertical networks. In order to do this, the extra time and money should be invested by biogas owners.

The case study analysis showed that the lack of follow-up service was the most important issue that small-scale biogas plants experienced in SSA. According to Ghana's case study, the lack of written agreements between the owners and the biogas service companies allowed the latter to feel free to not give any after-sale service. In addition, the lack of communication between them created a general environment where the owners don't have enough knowledge to fix the issues occurred by themselves and the lack of assistance from the biogas service providers lowered the user's interest to maintain properly their biogas plants. As a result, the business environment makes extra hard the maintenance of biogas plants that relies only on the owner's force since the lack of anonymous trust broadens the distance between customers and suppliers, or users and biogas companies.

Moreover, the lack of proper national programmes on biogas technology represents a crucial factor for the success of biogas projects in SSA. An example of this was seen in the Ghanaian case study, where despite the involvement of more than ten biogas companies in the promotion and construction of biogas plants, the lack of cooperation with the national government made the investment costs very high and most of the communications between providers and users terminated as soon as the systems were installed. In South Africa, the bureaucracy was still very high, despite the introduction of the Independent Power Producers (IPPs) and new regulations for the development of new biogas projects. In this way, the lack of transparency leads to the lack of control on the investments made by the government that sometimes were burnt before reaching the goal desired.

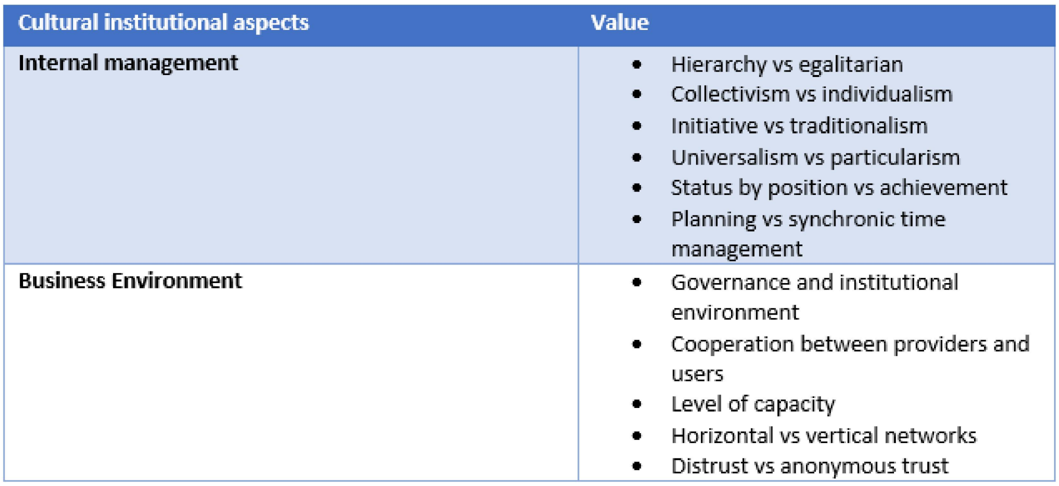
e) *Which parameters can be used for the development of the evaluation assessment that characterise the performance of small-scale biogas plant and what is their interconnection?*

The parameters that characterise the evaluation assessment are listed in two tables described below in figures 6.1 and 6.2.



Assessment Criteria	Indicator
Technical	• Reactor design • Design Organic Loading Rate • Design gas production • Construction materials
Operational	• Reactor maintenance • Actual Organic Loading Rate • Hydraulic Retention Time • Solids Retention Time • Feedstock characteristics • Reactor temperature

Figure 6.1: Technical and operational indicators for the performance characterisation of a small-scale biogas plant



Cultural institutional aspects	Value
Internal management	• Hierarchy vs egalitarian • Collectivism vs individualism • Initiative vs traditionalism • Universalism vs particularism • Status by position vs achievement • Planning vs synchronic time management
Business Environment	• Governance and institutional environment • Cooperation between providers and users • Level of capacity • Horizontal vs vertical networks • Distrust vs anonymous trust

Figure 6.2: Cultural institutional values as preconditions for the performance of a small-scale biogas plant

In terms of technical indicators, reactor design is considered one of the most important due to the high occurrence frequency of gas leakages in the biogas plants of the case studies. In addition, the design OLR and gas production are very important because most of the time was observed a mismatch between the designed digester capacity and/or the locally available feedstock with the actual user needs. These aspects influence the interest of biogas users to invest time and money for the proper maintenance of their biogas systems. The last technical indicator is "construction material" since the plant necessitates of materials that are gas-tight and locally available, with the support of anti-corrosive coating and regular checking.

For the temperature, usually, biogas owners in SSA don't pay so much attention because even during the coldest season the temperature doesn't decrease so drastically. However, the control of this parameter is necessary for the stability of the biogas process. The operational indicators introduced are directly related with the technical one since operational issues, such as inlet pipe blocked, irregular feeding of the digester, or biogas appliances corrosion, can generate alteration of the technical parameters. The blockage of the inlet pipe causes a drastic drop of the organic loading rate and the pH inside the digester, while a mismatch with the design gas production can occur if the biogas produced is hindered.

The evaluation assessment takes into consideration also the internal management parameters because proper maintenance of the biogas plant is also affected by good management of the workers by the biogas owners. In the case studies aspects like negligence of the workers, lack of practical knowledge, lack of motivation, lack of initiatives, lack of planning were mentioned and they can be all connected with the parameters developed. Through the analysis of the issues, it was possible to observe that these aspects affected the maintenance of the biogas plants because the productivity and efficiency of the workers were limited by the presence of power distance with the owners, a lack of dialogue, status by position and a lack of interest of the owner.

The internal management and the operational maintenance of the biogas plants were affected by the business environment. Lack of follow-up service from the biogas companies induced the users to lose their interest in maintaining properly their plants due to the lack of own practical knowledge on biogas technology. Vertical networks and distrust characterised these dynamics and the lack of support from the government allowed the biogas companies to interrupt the connection with the users as soon as the installation was completed. From the findings in the literature and case studies, the government is fundamental for the promotion of the biogas technology, through practical demonstrations, financial supports, policy framework, and the cooperation with all the stakeholders involved in the biogas business. The lack of knowledge and the lack of interest are the principal causes of operational issues such as a discontinuous feeding, a not efficient stirring, filtering and cleaning system. The internal management of the workforce is also affected by the lack of knowledge because workers are not confident to take initiatives or share individual opinions, and the owners are not willing to organise the several activities with an optimal planning time management.

f) *What recommendations for the performance improvement can be provided on the basis of this analysis?*

Several recommendations were developed in the light of what it was explained in the case studies. First, better communication between biogas providers and users should be established, in order to provide to potential biogas owners training workshops and manual guidelines for a proper maintenance system and regular check-up on the biogas plants performance. Secondly, the installation of the biogas plants should comply with the user's capacity. The amount of feedstock that a potential biogas user can supply to the digester is a crucial aspect that biogas providers should consider during your planning installation step, as well as the possibility of using and selling the system's products. In addition, the location of the biogas plant should fulfil several conditions to guarantee the suitability of the location. A suitable installation of the biogas plants should be taken into consideration due to the fact that most of the malfunctioning biogas plants were affected by gas leakages, mostly generated by a structural defect of the plants. The third aspect to implement is the amount of water available for the correct feeding of the biogas plants, especially in terms of water collection because it can be very time-demanding. Appropriate maintenance of the plant is necessary to avoid all the operational issues that affect the performance of the biogas plants, and it requires first the interest of the biogas owners and second a good level of discipline and routine from them. In addition, a sufficient monitoring system is suggested in order to provide useful data to biogas providers and users for the detection of possible issues and for some evaluations that could improve the biogas technology. Practical knowledge and experiences on biogas are very limited in SSA and the government, with the cooperation of NGOs and other organisations, should invest significantly in training programmes. For this purpose, the development of a National Programme on biogas technology is fundamental to encourage potential biogas users to install biogas plants and to provide to them the sufficient knowledge to maintain properly the system and obtain the maximum benefits from it. The last recommendation is that biogas owners should invest more energy and time on developing a composition of teamwork and remuneration as an internal management style to create more egalitarian cooperation between them and the workers and optimise the productivity of the latter ones.

6.2. Reflection and limitations

This section will describe the limitations encountered during the research and how these limitations were tackled. First, it will reflect on the barriers experienced during the literature research and the field research in South Africa, for the case study development. Second, it will argue the limitation of the data analysis. Lastly, this section will discuss future research that could be developed to improve this work.

6.2.1. Reflection on the data collection

The theoretical and empirical data was collected through the literature research and the personal experience in South Africa by interviewing several stakeholder experts on biogas technology, and by visiting five small-scale biogas plants. Prior to travelling to South Africa, communication with Nickey Janse van Rensburg from the PEETS department of the University of Johannesburg was already established. Her connection turned out to be crucial to get into contact with local biogas owners and local stakeholders. In addition, the most important contribution that I received came from Samson Masebinu a PhD student from UJ that organised several meetings with local biogas experts. Nonetheless, one of the first and main barriers encountered was the lack of big and organised network in South Africa of biogas owners and provider, and the limited opportunities to contact NGOs or local farmers involved in the biogas context. In contrast to Western Europe, many biogas companies or biogas owners do not have a website and it was very challenging to find the right telephone numbers to establish communication with them. For this purpose, informal networks were fundamental and reaching the rights contacts were very time- and energy-consuming. In addition, the South African lifestyle is somewhat slower compared to the European and it took time before arranging meetings and visits. As a result, it took around two weeks before the first two visits were organised, while the last three visits were conducted in the last two weeks of my accommodation. On the other hand, the South African people were generally willing to help, and the first stakeholders interviewed introduced the researcher to other biogas experts, generating a sort of snowball effect to find new interviewees.

Another limitation was the scarce approachability of the biogas plants since the majority of them were located in rural areas and the only solution was to use the car of the university. During the interviews with some biogas owners in rural areas, an evident language barrier was experienced. In these specific situations, misunderstandings were frequent in both ways, which periodically led to ask the same question twice trying to be more clear. Moreover, the researcher observed a mismatch between the answers received from the respondents and the actual practices. They occasionally showed to be aware of the most desirable practices and answer but they were not able to improve these practices. On top of that, the lack of proper bookkeeping of the several daily activities occurred in the biogas plants hindered the researcher's opportunity to check if their answers were representing the truth.

The last issue encountered by the researcher was the investigation of additional case study through the literature research. It was very challenging to find adequate scientific documents that were describing the operational conditions of biogas plants in the Sub-Saharan Africa context and the internal management and business environment analysis at the same time. In addition, the interviews were completely dependent on the researcher both for the conduction and the interpretation. As a result, the case study description and analysis were limited by the completeness of the researcher's work and it was necessary to differentiate the objective analysis from the subjective interpretation in order to develop the most unbiased analysis as possible.

6.2.2. Reflection on the data analysis

The analysis is based on five case studies, each including a substantial amount of data. A large number of commonalities in the description of the issues among the cases was observed, as well as some differences, and the findings were supported by these aspects. However, the research had to deal with some limitations during the analysis.

The first limitation regards the qualitative aspect of the case study analysis using interviews and description made by other researchers. The analysis can be for instance subjected to inaccurate interpretations, misunderstood expressions, false answers, and different point of view. Moreover, it is difficult to generalise the research despite the big amount of information gathered from the interviews, due to a relatively small sample. The geographic and socio-cultural environment of the case studies were very specific, and a way higher amount of sample is necessary in order to depict a general biogas context in Sub-Saharan Africa. Nonetheless, within the three months of field research in South Africa and one month of literature research, 5 case studies were described and analysed that provided a reasonable amount of data, from which valid conclusions could be developed. On top of that, all the findings were continuously discussed and examined closely during the work period by the researcher, local people and biogas experts.

To accommodate the generalisation, the scope of the thesis was limited by the researcher. The focus of the thesis was on small-scale biogas plants operating in Sub-Saharan Africa. Biogas plays an important role for the sustainable development of poor communities that cannot afford traditional energy sources and it is crucial to understand how the biogas owners are using this technology to enhance the system's efficiency and performance. Moreover, an analysis was made on the internal management adopted by the biogas owners in their plants. Understanding their practices and the hindrances generated to their workers is important to improve the professional attitude among the workforce that affects consequently the maintenance and the performance of the biogas plant. Observing some deficiencies of the business environment in the case studies was also crucial to comprehend the adequate conditions to improve and enable the correct development of the biogas technology in SSA. The literature on biogas in SSA presented in many documents similar findings while locating in different countries with different contexts. It is thus expected that the findings of this research are applicable to small-scale biogas plants of other developing countries as well. However, it is advisable to limit the applicability of the results to small-scale biogas plants and other parts of the African continent.

6.2.3. Recommendations for further research

This research achieved thorough analysis of the main issues that affect the performance of small-scale biogas plants in Sub-Saharan Africa and it gave recommendations with potential solutions to improve their efficiency. While it provides a relevant amount of information and answers about the biogas technology development in SSA, it arouses additional questions that should be explored in future research.

This research developed an assessment criterion that provides a tool to evaluate the performance of small-scale biogas plants in SSA and to analyse the internal management and the business environment around them as well. Analysis the aforementioned case studies, some differences in biogas maintenance and internal workforce management were observed, due to differences in educational backgrounds, geographical area, cultural and economic environment and government establishment and besides, these differences are highlighted between plants in the urban areas and the rural areas. Firstly, comparative researches could analyse these and other divergences in order to develop additional indicators and drivers for the biogas performance. For instance, future research could examine one specific area, such as a specific type of digester, or determine the differences between small-scale biogas plants performing in the rural areas and urban, as it is expected that plants in rural areas will rely more on a traditional management system and lower financial capital. Moreover, the assessment criteria could be applied to specific countries or regions of the SSA, since the weight of each parameter on the biogas performance, especially for the socio-cultural one, changes with the type of environment that characterises the country. Kenya, as well as South Africa, is economically more mature than Tanzania, but biogas technology is still struggling to diffuse within the country, and this tool can be used to analyse the commonalities and divergences with the other African countries.

Secondly, this research is limited to biogas plants that are failing or partially operating. A future study could compare unsuccessful biogas projects with fully productive biogas plants in order to confirm or modify the assessment criteria previously developed and to provide additional recommendations for the optimal performance of the technology. A big limitation encountered during this research was the limited amount of case studies analysed. This aspect hampers the generalisation of the results. The research could be improved by conducting more interviews and plant visits, and if needed by finding more case study description in literature. In addition, about the interview's questionnaire development the questions should be focus specifically on the topic of the research and should answer the main research question of the thesis work. A lot of information is it possible to get more indirectly by starting with the technical issues and a description of the daily production process.

Lastly, a big part of the research was investigating the internal management of Sub-Saharan African biogas plants that was playing an influential role in the performance of the plant itself. However, literature could not provide enough data on this topic related to the biogas technology, but it is evident that a pre-condition for proper maintenance of the biogas plant is the professional attitude and the motivation of the people in charge of the maintenance activity. Even though this thesis work addressed the issue and provided evidence on the straight connection between 'internal management' and 'business environment' preconditions and the performance of the biogas plants, more research on this subject will be necessary to tackle this socio-cultural barrier among Sub-Saharan African biogas owners.

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