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Barriers to successful implementation of small-scale biogas technology in Southern Africa: What can be learned from past initiatives in Mozambique?

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ABSTRACT

This paper examines common barriers limiting the implementation of small-scale biogas systems in rural Southern Africa through a literature study and a case study of six small-scale biogas digesters installed in Maputo province in Mozambique. The study strives to understand why the implementation rate of small-scale biogas systems in rural Southern Africa is so limited despite favourable conditions. The literature study identified several common barriers to the successful implementation of small-scale biogas in rural Southern Africa related to financial, technical, socio-cultural, and institutional issues. The case study results show that only one digester was operational, and five failed and were abandoned. Low technical ability of constructors results in poor-quality installations. Lack of technological know-how and local capacity for operation and maintenance of digesters are primary reasons for the failure of the digesters. Possible solutions are to intensify research, demonstration, dissemination and application of small-scale biogas; adapt the design of biogas digesters to the local context, meeting the needs of users and using locally available materials; sharing knowledge and information about small-scale biogas technology and its potential would contribute to improving the rate of successful implementation in Southern Africa.

Keywords: small-scale biogas systems, anaerobic digestion, barriers, southern Africa, Mozambique

1. INTRODUCTION

The electrification of Africa is far behind the rest of the world, with an electrification rate of about 43% and over 80% of its rural population being electricity-deprived. An increasing population adds to the problem, with over 600 million Africans still living without access to electricity [1,2]. However, the situation in countries like Ghana, Kenya and Rwanda is more optimistic, estimated to reach full access by 2030 [1]. In the same report, IEA [1] concludes that mini-grids and stand-alone solar-based systems are the most viable solutions to mitigate electricity deprivation in rural areas in Africa.

In Rural Southern Africa, the populations have low electrification rates, and cow dung, crop residues, fuel wood, charcoal, and paraffin are the primary energy sources for domestic use [3-5]. In Mozambique, over 95% of the population still depends on biomass like firewood and charcoal for cooking and heating [6]. These biomass resources, in turn, negatively impact health and the environment. The demand for firewood and charcoal has been increasing while wood resources are declining [7]. The inefficiency of traditional biomass stoves is a significant source of air pollution. It is associated with severe health problems due to exposure to air pollutants [3,4]. In addition to health impacts, collecting and using these biomass resources as fuel has caused adverse effects on the environment and socio-economic development, such as deforestation, soil erosion, and associated flooding [3].

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Access to modern, sustainable, and more efficient renewable energy systems can positively contribute to meeting the population's domestic energy needs and the environment.

The agriculture sector is the backbone of economic and social development in Southern African countries and generates large amounts of bio-waste [4,8]. Agricultural waste includes crop residues, animal dung and slaughterhouse waste [9]. In addition, countries in Southern Africa produce large amounts of municipal waste (solid waste, wastewater, and human excrement). All these bio-wastes could be used to make biogas via anaerobic digestion. Biogas could significantly contribute to the energy system in Southern Africa, particularly in rural regions, by providing clean fuel for cooking, heating, lighting, and electricity generation, which minimises energy poverty. In addition, the digestate can be used in agriculture as fertiliser [3-5,8].

In large parts of Southern Africa, the climate is tropical, and the temperature is between 15-40°C most of the year [8]. According to the same author, low temperatures do not persist for long periods, even in subtropical areas. This makes anaerobic technology less expensive, not requiring any additional heating of the biogas reactor, which makes it possible to operate the anaerobic reactors with convenient organic loading rates [8].

Mozambique has favourable conditions for biogas production. The country's climatic conditions are suitable for biogas production, with average maximum temperatures ranging from 25 to 30°C in the summer (October to March) and between 15 and 21°C in the winter (April to September). In some areas, extreme temperatures above 40°C are expected during the summer. About 67% of the population lives in rural areas. Smallholder farming essentially drives the agriculture sector in Mozambique. Agriculture is the main livelihood for 80% of the people and contributes to the overall national economy with approximately 31.5% of the Gross Domestic Product. The distribution of wealth is uneven, with the rural population being poorer [10].

Studies from other parts of the world with similar conditions as in Southern Africa suggest that biogas production from small-scale biodigesters can contribute to the energy system for households in rural, unelectrified areas of Southern Africa. Small-scale biogas technology has been promoted in Africa for decades as a viable contribution to sustainable energy production, alleviating energy and environmental issues, and contributing to food security [3,11,12].

China and India are two countries where implementing rural biogas programmes has led to significant economic, social, and environmental benefits. In both countries, the agricultural sector significantly contributes to carbon emissions, stimulating an increasing practice of circular agriculture and cleaner production while capitalising on resource efficiency and energy recovery [13]. China and India have led by installing millions of family-size biogas digesters in rural areas [9]. China and India have extensively utilised biogas as an energy source and fertiliser for soil enhancement since the 1950s [8]. China's recycling programmes focus on generating electricity, organic fertiliser, and biogas from manure [14].

It is expected that small-scale biogas technology can contribute to the energy system in rural, unelectrified areas in Southern Africa and could lead to self-sufficiency in household energy provision for cooking and lighting. This will enable better environmental management and boost economic development in Southern Africa [4]. National biogas programmes have been established in Kenya, Uganda, Ethiopia, Tanzania, Rwanda, Cameroon, Burkina Faso and Benin [15]. However, the biogas sector in Southern Africa develops far slower than in other regions [16]. Several studies [3,4,8,9,11,12] show that despite favourable conditions, the implementation of small-scale biogas systems in rural Southern Africa is limited.

The objective of this study is to investigate what barriers contribute to the limited performance of small-scale biogas systems in rural Southern Africa and to present possible solutions that can contribute to more successful implementation based on a case study from the rural outskirts of Maputo, Mozambique. To address the objective, the following research questions were investigated:

- What are the most common barriers limiting the implementation of small-scale biogas systems in rural Southern Africa?
- What can be learnt from small-scale biogas digesters installed in rural Mozambique to improve the rate of successful implementation in Southern Africa?

The results are presented and discussed in both regional and local contexts.

2. METHODS

2.1 Literature study

A literature study was conducted through the Scopus database searching for peer-reviewed articles using search terms related to barriers for small-scale biogas systems and Southern Africa. The literature study provides an overview of common barriers to successful implementation. Only literature published during the last 15 years was selected.

2.2 Case study

Six installations of small-scale biogas systems in rural Mozambique were investigated. One digester installed at National Institute of Agronomy in Chobela – "Centro Zootécnico de Chobela" (Magude district, 25°00'17.8"S, 32°43'59.6"E). One digester installed at a household in the village of Magude (25°01'54.9"S, 32°37'28.63"E); One digester installed at Frangos de Mahubo chicken farm in Mahubo (26°08'22.3"S, 32°20'34.4"E), District of Boane; One digester installed in Centre for Research and Transfer of Agricultural Technologies of Umbeluzi (CITTAU) in Boane District; One digester established at One World University (OWU) in the District of Namaacha; and One digester installed in Municipal Slaughterhouse District of Manhiça.

Semi-structured interviews were held with owners and operators of the assessed small-scale biogas systems to gather information about their origin and function, identifying problems and challenges with the systems. The specifications of the plants and the results of the interviews are presented in Table 5.

3. RESULTS

3.1 The most common barriers to successful implementation of small-scale biogas systems in Southern Africa

The most common barriers limiting the implementation of small-scale biogas systems in rural Southern Africa may be financial, technical, socio-cultural, and institutional barriers [3]. A summary of barriers identified in the literature is presented in Table 1 – 4.

Table 1. Financial barriers for small-scale biogas systems in Southern Africa.

Financial barriers	**References**
High installation and investment costs for conventional biogas systems	[3,4,8,9,12,15,17]
Lack of flexible credit schemes and other financial support for potential biogas users and entrepreneurs to invest in start-up biogas businesses	[3]
The inability of potential biogas users and entrepreneurs to take advantage of international carbon credit schemes	[11]
Competition from firewood - where the wood collection is free and available or cheaper	[3,11]
Low income of individuals makes it impossible to invest in digester system and, above all, to maintain it operational	[8]
Lack of local capacity and funds to purchase equipment, components, and spare parts with scarce foreign currency	[8]
Long payback period associated with the technology of the installation of household-level biogas digesters	[9]

Table 2. Technical barriers for small-scale biogas systems in Southern Africa.

Technical barriers	**References**
Lack of documentation and operating instructions	[3]
Poor design, construction, and quality of installed units, inadequate for local conditions and users	[3,5,8]
Insufficient availability of water for biodigester operation	[3,8,9,18]
Insufficient feedstock	[3,5,8,9,11,12,15,17]
Daily operations are too time-consuming for operators	[11]
Reliance on expensive imported construction materials and spare parts	[3]
Incorrect operation and lack of maintenance due to lack of local technical skills	[3,8,11]
Limited or no follow-up services by installers and poor monitoring and maintenance of existing digesters	[3,11]
Lack of knowledge, experience, information, and training of consultants, contractors, and potential biogas owners or installers and operators	[3,5,8,11,15,17]

Table 3. Socio-cultural barriers for small-scale biogas systems in Southern Africa.

Socio-cultural barriers	**References**
Poor social acceptance. Preference for cooking with a firewood stove instead of a biogas stove	[3,8]
Inertia towards change and new technology	[3]
Competition with other traditional uses of feedstock materials, such as cow dung	[3]
Social/cultural/religious/health resistance or objection to handling or using animal or human waste for biogas production and the subsequent digested sludge	[3,8,11,18]
Cattle and other livestock roam in open fields, making dung collection for biogas unfeasible	[3,8,15,17]
Change in the traditional energy use decisions	[3]
Low literacy levels make the adoption of the technology more difficult	[3,8]
Lack of awareness about the technology and its potential benefits	[3,8]

Table 4. Institutional barriers for small-scale biogas systems in Southern Africa.

Institutional barriers	References
Insufficient government support and lack of incentives	[3,8,15]
Lack of regulations or clear biogas policies to produce and commercialise biogas	[3,8,15]
Ownership and responsibility of the biogas system are not well-defined/understood)	[3]
Limited governmental capacity (budget) or donor investment in biogas for research and to assist with funding	[3,11]
Uninformed or poorly informed authorities and policymakers	[8]
Low institutional capacity to implement a national biogas programme	[11]
Lack of up-to-date information and knowledge sharing of biogas research at national, continental, and international scales	[3,15]
Research at universities is frequently considered to be too academic	[8]
Lack of adequate collaboration and coordination between public institutions, private sector and potential users	[3,8]
Limited infrastructure makes access to rural areas difficult for construction.	[3]
The interplay and relationship between owners, funders, and providers is a crucial determinant of success or failure, with the owner being the most critical factor, as their willingness and ability to engage with the systems seems directly correlated to outcomes	[10]

3.2. Case study biodigesters in Maputo Province

Table 5 presents the assessment results of small-scale biogas digesters installed in Maputo Province, Mozambique. The table summarises each case, the entity that installed the digester, the year of installation, the type and size of the digester, the type of feedstock used, the current state, and problems and challenges.

Table 5. Results from assessment of biogas digesters in Maputo Province.

Case	installer	Year	Type	Size	Feedstock	Current state	Problems and challenges
A. National Institute of Agronomy in Chobela	Pedagogical University.	2019	Tank digester	2x0.25m^3	Animal dung	Not operating	- Test digester for research. The gas was not utilized. - When researchers left the unit was dismantled.
B. Household digester in Magude	Ministry of Energy and foreign crew	>10 years ago	Floating dome digester	>5m^3	Animal dung	Not operating	-Not properly designed and constructed, only 2 guiding poles for the gas tank, gas pipes were flexible and underground. -System functioned well for several months. Problems with using the gas in the kitchen. The digester was abandoned. - Unit could be rehabilitated.
C. Frangos de Mahubo chicken farm	Supplied by Chinese company PUXIN, installed by the farm owner	2021	Tank digester	3x15m^3	Chicken manure	Operatin g poorly	- Chicken manure collected by mechanical scraper on a concrete floor, is therefore free of sand and bedding. - Manure is mixed with water from toilets and used as feedstock. - Gas is used to heat stables and for cooking. The slurry is used as fertilizer by the farm owner. - Operational data of the unit are unknown. There is no measuring of the quantity of manure and water entering the unit. - No water traps in the gas distribution unit, could cause problems with condensation - Produces biogas below maximum capacity.
D. Centro de Investigação e Transferências de Tecnologias Agrárias de Umbeluzi (CITTAU)	Installed by Chinese as part of a cooperation program	2015	Flexible PVC digester	10m^3	Unknown	Not operating	- Closed since 2018. Operators of the biogas system were transferred to China. - After the field visits, the owners have expressed interest in making it operational again.
E. One World University (OWU)	One World University (OWU)	Unkn own	Lagoon digester	Unknown	Unknown	Not operating	- Not operational since 2018. - After the field visit, the owners have expressed interest in making it operational again.
F. Municipal Slaughterhouse District of Manhiça	Municipality of Manhiça	2016	Lagoon digester	Unknown	Slaughter waste	Not operating	- Not operational since 2017 -The Association has shown interest in seeing the biodigester repaired but needs funds for the reparation service. - They have requested the training of two employees responsible for the digester operation.

4. DISCUSSION

Over the past two decades, different biogas projects have been implemented in several Southern African countries, often by international third parties (international aid agencies and donors), African governments, and private individuals to promote sustainable development in developing countries. However, implementation of small-scale biogas systems in rural Southern Africa is limited. The ruins of hundreds of failed and abandoned biogas projects are found in the region [11].

In most biogas projects in Southern Africa, biogas is produced through anaerobic digestion using the Chinese fixed-dome digester or the Indian floating dome biogas digester. According to Parawira [8], these systems are unreliable and, in most cases, perform poorly. In Mozambique, in addition to the Indian floating dome biogas digester, biogas is produced through Tank digesters, Flexible PVC digesters, and Lagoon digesters. All these biodigesters have short lifespans due to poor quality, inadequate design and construction, poor operations, and lack of local capacity for maintenance and repair.

The findings from the case study in Maputo province confirm that little investment in small-scale biogas systems is taking place in Mozambique. However, governmental institutions, especially international aid agencies and donors, have invested in projects that mimic biogas projects that have been successful in rural areas in other parts of the world, such as China and India. The limited success of small-scale biogas systems in Maputo province has not contributed to any spread of biogas technology throughout the country. Of the six investigated small-scale biogas systems in the Maputo province, only one is operational, and five have failed. The five systems that failed are now abandoned and have fallen into disrepair. Even so, the owners of these abandoned systems have expressed a willingness to see the systems rehabilitated and operational again. Based on the assessment, the lack of technical know-how and local capacity for the operation and maintenance of digesters is the main reason for the failure of these biogas projects and consequent abandonment by users. For example, CITTAU is a research unit from the Ministry of Agriculture and Rural Development dedicated to training and technology transfer to provide a service of excellence to agricultural producers in Mozambique. The small-scale biogas system ceased working and was later abandoned shortly after the people who operated the biogas system and produced the biogas returned to China. In the National Institute of Agronomy in Chobela – "Centro Zootécnico de Chobela", cooking is done mainly with charcoal, which could be replaced with biogas if the system was operational. Even the biogas plant that was found to be in operation, the biodigester at Frangos de Mahubo chicken farm, is not producing biogas according to its maximum capacity. The lack of technical know-how and local ability to construct these small-scale prefabricated systems, operation and maintenance contributes to the poor biogas production.

The case study revealed that three (Case B, C and F) of the six cases failed due to a lack of local capacity and funds for maintenance. This is similar to what Kalina [11] and Parawira [8] reported, stating that finance and human capacity are significant barriers.

The literature review identified a lack of documentation and operating instructions [3], poor design and quality [3,8], and Incorrect operation [3,8,11] as significant technical barriers. Similar challenges were reported in all of the cases investigated.

The literature identifies that lack of knowledge, experience, and training of owners, installers and operators [3,8,11], limited follow-up by the installers of the systems and no remote monitoring and maintenance [3,11] are significant technical barriers. The results suggest that these factors also have contributed to the failures and abandonment of the investigated systems in Maputo Province.

The literature review shows that insufficient government support, lack of incentives [3,8], and not well-defined/understood ownership and responsibility [3] are essential factors for successfully implementing small-scale biogas systems. This is also reflected in the case studies where unclear ownership and poor collaboration between key stakeholders, e.g. owners and operators, funders, service providers and finance institutions, contributed to the failures.

On the other hand, in the literature, lack of feedstock and water is often seen as a barrier. This was, however, not a limiting factor in the cases investigated in Maputo province.

4.1 Possible solutions to identified barriers

Several possible solutions to the barriers preventing the successful implementation of small-scale biogas systems in Southern Africa are identified in the literature and through the case study.

<u>4.1.1. Possible measures to overcome financial barriers</u>

Sharing reliable and relevant information about biogas technology and its potential to local authorities, politicians, and the public in general [8,15].

Financial institutions must facilitate the provision of loans.

Provision of several financial incentives (subsidies) by the government or international organisations and industry for pilot-plant and demonstration-scale projects to accelerate and increase the biogas applications in the country [8]. Subsidies are justified to compensate for the difference between the ability to pay for a digester and the social benefits resulting from its adoption (maintenance of forest cover, prevention of land degradation, and reduction in emissions of greenhouse gases) and private benefits (reduction in expenditure for firewood and kerosene, savings in time for cooking and firewood collection and health) accruing to users [8].

Government support for biogas projects in the country, providing funding in collaboration with donors as part of its crucial policy objective to increase access to affordable and reliable energy services and stimulate productivity [3].

Preparation of small-scale projects to obtain support from nonprofit international organisations and agencies [8].

Support potential private investors (private companies) by offering a governmental partnership in biogas technology production [8].

The long payback period associated with the technology of the installation of household-level biogas digesters can be reduced by adopting the community energy system (community-level biogas digester) involving anaerobic co-digestion [9].

4.1.2. Possible measures to overcome technical barriers

Sharing knowledge about the biogas technology and its potential with local authorities, politicians, and the public in general [8].

Sharing of knowledge among biogas projects in Southern Africa.

Knowledge transfer from research centres and universities to state sanitation companies and private companies in the agricultural sector, consulting engineers firms, governmental departments, government environmental control agencies and biogas users to improve technology dissemination and appropriate use [3,8].

Encourage training and capacity-building programmes [8].

Training skilled labour, owners, operators, and technicians of biogas digesters in technical know-how about design, construction, operation and maintenance of digesters.

Training and accreditation for biogas masons through short-term biogas system construction and supervision courses [3].

Support and increase of research, application, development, training and demonstration for the development of biogas technology [8].

Further research to optimise production, support policy development and improve the uptake of biogas technology.

There is, therefore, a need to introduce more efficient digesters to improve both the biogas yields and the technology's reputation [5,8]. Adapt the design of biogas digesters to the context and needs of users. Using local materials to construct small-scale biogas digesters can overcome dependence on imports of expensive small-scale prefabricated systems, construction materials and spare parts. A well-designed Chinese fixed-dome digester or modified Chinese fixed-dome design would be a better model biodigester option for most Southern African countries since it has a long lifespan of about 20 years (once installed, it has 20 years of operation) [3,5,12,18]. This design is deployed on the mono-feedstock-wet anaerobic digestion (WAD) principle. This operation principle sets a limit to the solid content of the influent (% TS of the substrate is less than 10%) with a very high water demand (up to 90% of digester volume) imposed by the designs. But the Chinese fixed-dome digester can also be operated towards the dry anaerobic digestion (DAD) principle (%TS of the substrate is greater than 10%), with relatively low performance, highlighting insufficient mono-feedstock and water scarcity for a sustainable operation of the design within the context of rural Southern Africa.

Furthermore, constructing, operating, maintaining, and repairing is relatively easy. Its construction only needs skilled labour, bricks, cement, sand, concrete, steel, PVC pipe, flexible plastic pipe with a copper inner lining and Safety valves. The most significant contribution to the investment cost of the digester is attributed to the gas storage facility (dome), skilled labour and cement. Generally, all materials, components and spare parts used in their construction, maintenance and repair are available locally and do not require funds to purchase with scarce foreign currency through imports abroad, which reduces associated costs [5,12].

It is necessary to learn from past experiences and adapt biogas technology from Asia and Europe to local realities [8].

The community energy system (community-level biogas digester) involving anaerobic co-digestion can be a more efficient option than a household system to overcome the insufficiency of substrate and labour incurred in resource collection and feeding due to the benefits of lower labour requirements for its operation and availability of different biowastes for sharing. Using a community-level biogas digester can be a better option and advantageous than those on a family scale [9,15].

To overcome the installer's limited or non-existent follow-up services, training and employing more technicians to provide follow-up services, including inspections and repairs, particularly in the first few months after the systems are installed, is necessary. On the other hand, it is essential to encourage users to contact installers immediately when problems arise [3].

To raise the understanding of appropriate operation and maintenance, simple operation and maintenance manuals in local languages should be prepared and distributed [3].

Farmers must have enough livestock to generate continuous biogas flows [8].

4.1.3 Possible measures to overcome socio-cultural barriers

Dissemination, demonstration and training centres or intensive educational and campaign programmes by distributing simple explanatory pamphlets, meetings with communities or using other media to raise awareness and remove social barriers [8,9].

Cattle and other livestock must be penned for effective collection of animal dung [8].

4.1.4 Possible measures to overcome institutional barriers

It is necessary to introduce suitable incentives through policies, programmes, legislation, taxes and financial subsidies to weaken the barriers. This has been practised in India, China and Europe [3,8].

Establishing a national institutional framework because the rate of successful implementation of small-scale biogas systems in rural Southern Africa cannot occur without the proper social, cultural, political and economic institutions to support adoption, dissemination and appropriate contextual innovation [8].

Governments must commit to renewable energy programmes, developing and promoting renewable energy sources [8].

5. CONCLUSIONS

The most common barriers limiting the implementation of small-scale biogas systems in rural Southern Africa are financial, technical, socio-cultural, and institutional. The local technological know-how in designing, constructing, operating and maintaining biogas systems is minimal. Installation costs, limited awareness, limited training for biogas technology users, insufficient government policies and regulations, and no incentives to produce and commercialise biogas are among the main barriers.

The case study showed that constructors have low technical ability, which results in poor-quality installations. The lack of technical know-how and local capacity to operate and maintain digesters is the main reason for the failure of the biogas projects in Maputo province assessed in this study.

Possible solutions to improve the rate of successful implementation of small-scale biogas systems in Southern Africa include supporting and increasing research, demonstration, dissemination and promotion of the technology; adapting the design of biogas digesters to the context and needs of users and using locally available materials to reduce the cost of technology; developing training and capacity-building programmes; sharing of knowledge and information; develop suitable policies, legislation as well as taxes and financial subsidies. These measures would contribute to aligning the economic, technical, social and regulatory contexts, which can serve as a basis to improve the rate of successful implementation of small-scale biogas technology in Southern Africa.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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