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A Sustainable Operational Method for Micro-Scale Biodigesters in South Africa

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Abstract**—***This paper proposes a sustainable operational method for micro-scale biodigesters in South Africa. The findings indicate a compulsory maintenance contract that ensures constant digester feeding for microorganism sustenance is essential. A routine maintenance plan to ensure that all digester mechanical failures are minimized is also recommended. It expected that the proposed sustainable operational method for this technology will contribute towards energy access to millions of people in South Africa and globally as well as achieving national sustainable development goals objectives. The methodology can also result in increased uptake of this technology even by those that are connected to the national grid as a way of reducing their energy bills. This paper also highlights the high cost of micro-scale biogas digesters is a key hindrance for small-scale biogas digester rollout.*

Keywords**—***micro-scale biodigester; biogas; sustainable operational method; energy poverty.*

I. Introduction

Energy is an essential element for stimulating economic growth, social development, human welfare and improving living standards. Over the years, dependence on fossil fuels has increased significantly, and concerns about greenhouse gas (GHG) emissions have also increased prompting an increase in adoption of renewables and other cleaner sources of energy [1]. Current world energy consumption is roughly about 15 terawatts (TW) and renewable energy only contributes about 7.8% of the total global energy supply [2]. Energy demand for Sub-Saharan Africa is approximately 4% of the global energy consumption, which does not match with the sub-Saharan Africa population estimated to be about 13% of global inhabitants [2]. Biomass can play a role in the transition to a low carbon economy. Biogas technology is a proven technology that can provide both electrical and thermal energy for use by households. This technology has been implemented in many countries and the successes and failures of biogas programs are well documented in the literature [3]. Micro-scale biodigester technology utilization has significantly increased in Asia although the uptake in Sub-Saharan Africa has, up to now, been sluggish regardless of national and international efforts aimed at supporting biogas technology adoption [4]. Uptake of this technology, as with other renewable energy technologies, depends on many factors some of which are country specific. The African national biogas programme which was implemented in nine African countries - resulted in a 44% increase in biodigester installations between 2011 and 2012 and

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the number of biodigesters that are operational is currently unknown since 60% of the digesters that were installed after 2007 have failed [5].

A failing biogas project, regardless of the size, has unfavourable consequences on the general perceptions and adoption of micro-scale biodigester technology. Proposing a sustainable operational method for micro-scale biodigester in South Africa comes as a direct response that seeks to understand the fundamental limitations for the successful implementation of micro-scale biodigesters in South Africa. Biogas plants provide critical advantages in the area of waste management and produce organic-rich by-products in the form of fertilizer. Various factors that hinder the uptake rate of household biodigesters are well documented in South Africa, however, the main challenge is limited feedstock and relatively low numbers of cattle in South Africa when compared to India and China who produce 28% and 19% (respectively) of cattle globally [4]. Another challenge is the unavailability of land and water. Most South African rural communities face water supply challenges. Another cause for a slow uptake is the lack of proficiency and awareness of the benefits of using biogas technology.

Economic development scenarios that are represented in this paper are attributable to identified domestic and communal micro-scale biodigester project options for households with four or more cows. Analysis of an economic and market model for a micro-scale biodigester showed that sustainable operation of a biodigester is cost-competitive to baseline energy sources such as fuelwood, cow dung, kerosene and Liquefied Petroleum Gas [6]. It is expected that the results of this work will contribute to the South African energy policy update in relation to the role of micro-scale biodigesters. Biogas programs have been rolled out by private companies, Non-Governmental Organisations and also by the Department of Energy (DoE) in some parts of South Africa, however, currently there is no clear policy framework and enabling instruments for sustainable biodigester operations. Analysis of the South African Gas Act 48 of 2001 only indicates digester registration as a legal requirement. This work will highlight the environmental and socio-economic benefits attributable to sustainable biodigester operation. This will also contribute towards the improvement of the livelihoods of rural dwellers that are still confronted with basic energy supply challenges.

This paper proposes a sustainable operational method for micro-scale biodigesters. It also analyses whether the rural population can afford to install micro-scale biogas digesters under the existing rollout models. Biogas production process should ideally be continuous and sustainable, hence the need for a working operational methodology for South African micro-scale biodigesters. The paper analyses the current economic and market models, policy framework and gaps in order to develop a viable operational method for sustainable usage of a micro-scale biodigester in South Africa.

II. Analysis of Factors Affecting Micro-Scale Biodigester Success

A study of micro-scale biogas projects implemented in the Eastern Cape Province revealed that about 65% of all digesters in the program considered in the analysis were non-operational and the main reason was associated with the operational issues related to micro-scale biodigesters [7]. The biodigester size considered in this study ranges from 1 to 12 m^3. The majority of the digesters under the program studied were structurally and mechanically solid, therefore, there were no issues related to poor quality of product or workmanship. Fig. 1 covers five possible root causes of digester failure in South Africa.

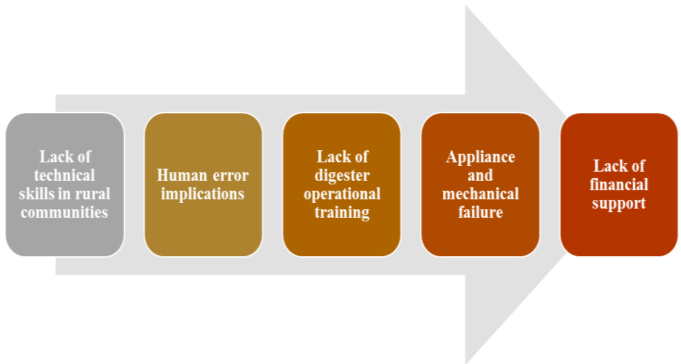

Fig. 1: Five factors affecting the lifespan of a micro-scale digester

Most of the biodigester failures are a result of either lack of operator technical skills or digester biology. For digesters to operate successfully and continuously, microorganisms need to be kept alive at all times [7]. A healthy state of microorganism depends on the category and amount of organic material fed into the digester, feeding frequency, the temperature a digester operates at, the availability of water (this is often a challenge is remote rural areas in South Africa), and lastly, ensuring that the pH of the digester is maintained within a permissible range. Failure to optimize and carefully manage parameters is a primary cause of digester malfunction. The majority of micro-scale biodigester beneficiaries do not have the required skills for digester maintenance or the knowledge to maintain adequate biodigester performance. A significant portion of biodigester projects installed in schools had champions who maintained the digesters used in the school feeding scheme i.e. providing cooking gas and bio-fertiliser for farming or gardening. Digester failure in schools, therefore cannot be attributed to a lack of operator involvement but to a certain extent a lack of technical skills as they became non-operation after the champions left.

Digester feeding is primarily dependent on human intervention. In this study, inappropriate feeding was found to have contributed a lot to digester breakdown [7]. If a digester is not fed correctly or not fed at all, for whatever reasons, microorganism populations will diminish and consequently, no biogas production will be generated [8]. Microorganisms can also die if detergents such as non-biological liquid, washing ingredients and fabric softeners are fed into the digester leading to digester biological failure [9]. Human-influenced error and biological failure rate have a strong correlation hence only about 22% of digesters installed before 2014 were still operational in the Eastern Cape at the time of the study [7]. The identified common cause was biological failure related to the human-influenced error. The person responsible for operating the digester has to ensure that the digester is operated in a sustainable manner. Biodigester breakdown was found to be attributable to mismanagement and poor operation of the digesters by the users [7]. It is critical to provide appropriate initial training to ensure that beneficiaries and specifically the future operators are left with enough knowledge to enable them to operate the digester with confidence in the long term. It can then be argued that biodigester installers should have expertise in the entire biological process of anaerobic digestion. Therefore, it is only logical to ensure that the biodigester infrastructure and maintenance becomes a responsibility of biodigester installers. While lack of training has been highlighted as a hindrance to the success of biodigester programs, this study reveals that lack of financial support for maintaining digesters is the main cause of digester failure in the Eastern Cape. For instance, some of the digesters in the area under study had damaged components such as damaged balloon digester storage bag, gas flow meter or gas extraction pipe(s).

Biodigester beneficiaries indicated that they did not receive any formal training, however, they were only taken through basic operational rules after construction was concluded [7]. The 65% overall failure found in the Eastern Cape case study is mainly attributed to assigning biodigester maintenance responsibility to digester end-users. It is therefore recommended that end-users be equipped with the necessary knowledge and skills that will enable them to operate the digesters in the absence of a contractor or donor maintenance contract.

The study found one biodigester that broke-down as a result of what could be categorized as a mechanical failure. A digester installed at (Mbawule) a school in Eastern Cape was found to be configured correctly, however, the school suspended feeding because the gas abstraction pipe was damaged. Other identified biodigester mechanical failures were attributed to blocked pipes, digester protection, gas and liquid leaks. During the reconstruction that took place at the school, some of the essential biodigester parts were never reinstalled [7].

Currently, there are no micro-scale biodigester installation regulations or a policy framework that regulates biodigester installations in South Africa. The Three Crowns High School biodigester is another example where mechanical problems, such as seized gears on the paddle wheels of the algae ponds were encountered. Another problem faced at the Three Crowns School was water supply shortage that resulted in an unstainable operation of the algal pond system [7].

The common cause of biodigester failure were found to be associated with lack of maintenance and most of the biodigester breakdowns could have been prevented if beneficiaries had received

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technical support from biogas experts. Access to financial support or necessary funds for experts to provide guidance and digester maintenance would resolve the higher digester failure rate. Inadequate funding is somehow linked to insufficient support given to digester beneficiaries as the contractors that install digesters do not have the budget for maintaining biodigesters beyond the installation and commissioning phase [7]. Micro-scale digesters installed in South Africa are generally donor-funded and therefore there are limited resources after the donor leaves. The communities are therefore left with no additional funding for maintenance. In some circumstances, contractors provide support at their own cost in an effort to build a good reputation for themselves with the hope that they will have an opportunity to install more biodigesters in future. Biodigester installation contracts should be packaged in a way that ensures digesters run smoothly [7]. Most of these projects are located in isolated parts and remote areas thus making the situation even more complex. Lack of funding came out as a major factor in the uptake of biodigesters by individual households who are left with no option but to accept donor-funded programmes which eventually fail due to lack of monitoring after commissioning. It is against this background that this paper proposes an operational plan that can be enforced through a complimentary policy or model to ensure that biodigester donors and contractors maintain installed digesters over their lifespan.

III. ANALYSIS OF AN ECONOMIC AND MARKET MODEL FOR A MICRO-SCALE BIODIGESTER

Micro-scale biodigesters in South Africa are generally donor-funded. Other projects are implemented through government-funded entities with an objective to encourage end-users to accept the technology though this approach has not had a great impact on the adoption of the technology and active market development [5]. In this work, the economics are based on the fact that most biodigesters have a lifecycle of between 25 and 30 years [10]. Based on the costs for the Three Crowns High School biodigester, by incorporating yearly inflation only and assuming other factors are constant, digesters could cost between R13 700 and R17 000 as indicated in Table 1. However, micro-scale digesters cost approximately R40 000 in South Africa [11].

Favourable biodigester pay back period (PBP) is attainable using the deenbandhu, KVIC, and janta model [11;12]. The deenbandhu model had the lowest PBP of approximately 4.7 and 1.6 years for a household micro-scale digester size of 1 – 6 m^3 respectively. The janta model was reported to have PBP of 11.3 and 3.2 years for biodigester sizes of 1 and 6 m^3 respectively, while a high payback period of 26.6 years was reported for a 1 m^3 floating drum digester. It is important to note that various models are used to calculate digester cost and benefits associated with using a micro-scale biogas digester. The Modified Basic Economic Evaluation Model used to assess the cost effectiveness of micro-scale biodigesters takes into account a number of parameters including optimum hydraulic retention time (HRT) which is 20 days [12].

TABLE I: MICRO-SCALE DIGESTER INSTALLATION ESTIMATION COST

Description	Quantity	Rate	Cost in Rand	Workforce cost	Cumulative at 6% inflation Amount in 2017
Groundwork	3.43	R100	R343		R486
Mould cost	1	R1 000	R1000		R1 418
Rotamoulded segments (4mx3mx7m)	3	R3 080	R9 240		R13 107
Welding of segments	3	100	R300	R180	R680
Paddlewheel platforms and pipping	2	300	R600	R400	R1 418
Total cost					R17 109

High micro-scale digester costs make digesters financially not viable, especially when compared with electricity connection fees prescribed - under the INEP (i.e. costing around R20 000 per connection). Based on recent quotations, a 6 m^3 micro-scale household biodigester currently costs up to R52 000 in South Africa excluding site visits and other costs while a biogas stove costs about R 1 750. These costs are high considering the low-income levels of most rural based South Africans, and this explains why biodigester programs are mostly donor-funded.

Poverty has been rising in South Africa, this is evidenced by the latest poverty statistics that

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indicate that South African poverty levels increased in 2015 [13]. Over 50% of the South African population were categorised 'poor' in 2015. The upper-bound poverty line (UBPL) in South Africa is R992 per person per month and approximately 30.4 million South Africans were living in poverty in 2015 [13].

The average employment and compensation ratio illustrated in Fig. 2 demonstrates that residents in rural municipalities earn less income compared to urban dwellers, this is due to socio-economic conditions and low skills levels existing in rural communities. Employment and compensation by skill average income earnings in Eastern Cape is about 22% (R 1.2 million) of Gauteng earnings (R5.3 million), this explains the earnings discrepancies between urban and rural illustrated in Fig. 2. Urban provinces have higher employment, compensation and skills rates, however, biodigesters are needed in rural areas where there is currently lower skills and employment rates, subsequently, lower affordability ratios.

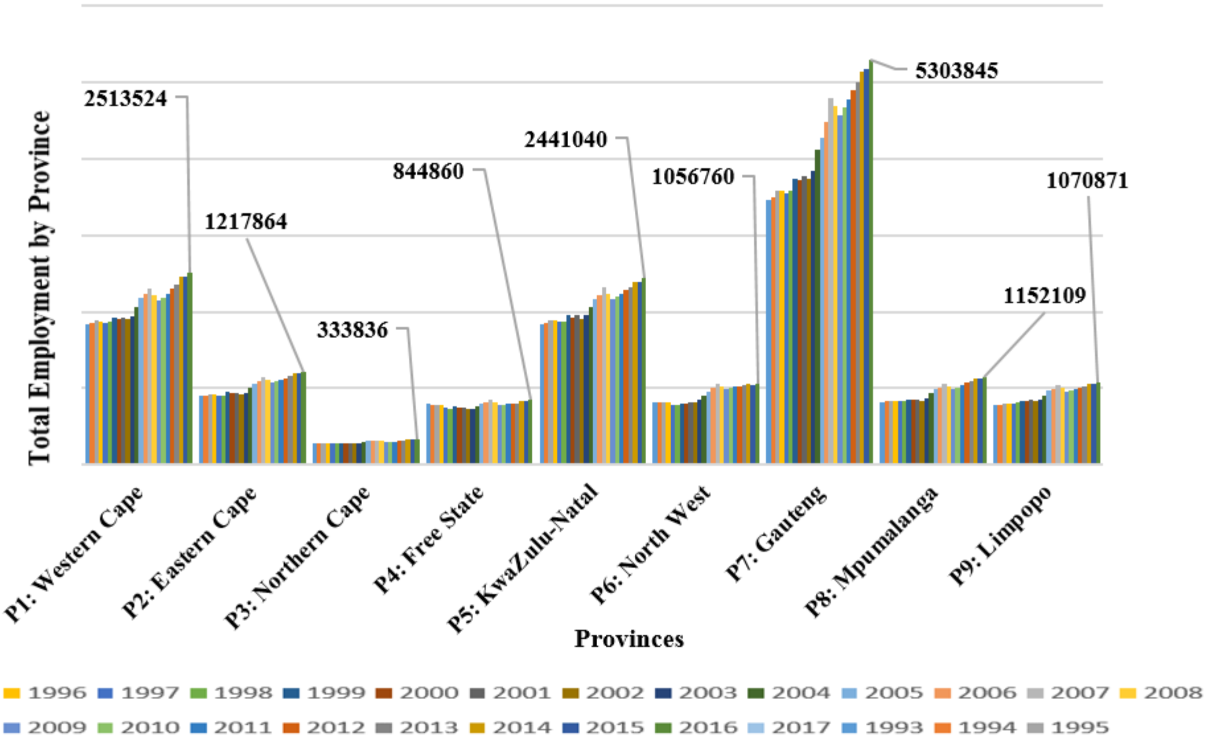

Fig. 2: Employment and compensation by skill ratio [17].

The income and expenditure for rural provinces are minimal, Fig. 3 indicates a low income and expenditure patterns in provinces such as Eastern Cape, Mpumalanga and Limpopo and Northern Cape. This means that residents in these areas are unable to afford to pay for biodigesters. In order for micro-scale digesters to be adopted in rural communities, government needs to regulate the digester cost and provide subsidies for rural dwellers. This will assist in curbing biodigester overpricing and make it economical while exorbitant pricing is managed through the provision of subsidies.

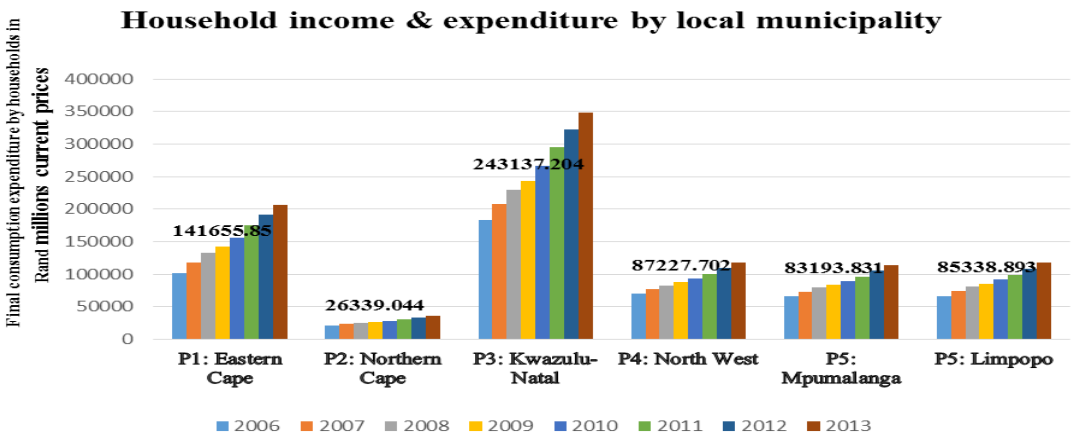

Fig. 3: Provincial income & expenditure [18].

In 2013, the biogas production industry gains some momentum, however, the lack of a policy framework was absent to sustain the development [14]. In 2016, the development of a national biogas strategy by the DoE provided some hope for biogas uptake, however, the strategy was retracted, therefore, currently, the existing South African energy policy does not cover micro-scale biogas digesters. This policy certainty in relation to micro-scale biogas digesters hinders the development of this technology. The South African Gas Act 48 of 2001 Schedule 1 and 2 lists small biogas projects in rural communities.

It highlights creating awareness, supporting the development of biogas infrastructure, registration of all gas production facilities and alternative access to energy in rural areas [15]. This policy instrument does not mention any funding plan although is refers to rural areas. The safety standards and installation guidelines regulation are also non-existent. These challenges need to be resolved. Although energy access is a recognised challenge in rural areas, the lack of energy in rural areas results in minimal economic activities. Gas only contributes about 2.5% of the South African energy mix**.** Imported natural gas (NG) is utilised for industrial sectors purposes, power generation, vehicular fuel and residential areas [15]. The current legislation poses the following challenges for micro-scale biogas:

- No definition of micro-scale biogas projects;
- Gas reticulation currently regulated by Municipalities – not within NERSA's jurisdiction;
- Act only mentions the transmission of gas for own use – distribution excluded.

IV. Proposed Sustainable Operational Method for Micro-Scale Biodigesters in South Africa

Micro-scale biogas digesters need to be sustainable since the potential of biogas utilization is measured against the codes of sustainability. In order to guarantee sustainable operations for micro-scale in South Africa, the following sustainable operational method illustrated in Fig. 4 is proposed. This operational method is designed to address issues related to digester failure identified in South Africa through this study. This is a proactive approach that draws lessons from how the general conventional power maintenance process in South African.

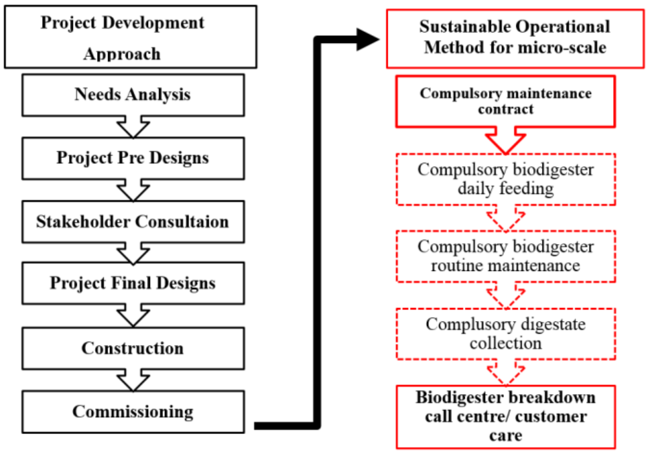

Fig. 4: Proposed sustainable biodigester operational method

Biogas generation is dependent on daily constant feeding and this has a direct impact on the biogas production process [16]. Micro-scale biodigesters utilise a through-flow feeding technique, this means that the digester operates throughout the day ideally with a constant feeding rate [16]. In the proposed sustainable operational method for micro-scale biodigesters indicated in Fig. 4, mandatory digester feeding should form part of the compulsory maintenance contract to ensure a constant feeding rate. For example, since feeding is required on a daily basis, there should always be someone available to feed the digester in the absence of a contract for feeding. Managing this through a contract would allow rotations in terms of the digester feeding teams thus freeing users from the burden of always being at home for feeding purposes.

Lack of biodigester routine maintenance is one of the causes of digester failure identified in this study which can be addressed in the maintenance contract. Implementing compulsory routine maintenance will certainly improve the success rate of micro-scale biodigesters.

The collection of the digestate should form part of the compulsory maintenance contract to ensure that biodigester beneficiaries are not left with the responsibility of removing digestate. Making digestate collection a responsibility of maintenance contractors will assist in reducing the actual maintenance contract cost since the digestate has monetary value. Biodigester operators should collect and resell digestate as a green fertiliser. In the context of sustainable consumption and production, some farmers indicated their willingness to pay a green premium for sustainable products such as the digestate. This approach will contribute towards achieving an upward trend in a digester success rate.

In order to address digester failure due to lack of technical skills and a basic understanding of the anaerobic digestion process, it is proposed that a digester customer care, in a form a Call Centre, should be established. Biodigester beneficiaries should then know who to contact if their digester malfunctions. This approach will ensure fast digester fault detection and parameter monitoring

V. Recommendations

It has been shown that the South African biogas industry is currently facing a number of challenges that hinder the uptake of the technology and also challenges related to supporting policies such as:

- Lack of sufficient awareness of registration requirements in the Gas Act;
- Many facilities already in operations prior to registration;
- Compliance requirements for individual households;
- Funding for biogas production facilities in rural households.

In the preceding section, a sustainable operational method has been proposed, however, it cannot work in isolation, there is a need to have a strong supporting policy. Micro-scale biodigester adoption requires a clear policy in order to ensure that all stakeholders are aware of their roles and responsibilities in the household biogas value chain. It is therefore recommended that a micro-scale biogas digester policy be

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established to regulate the following aspects, among others:

- Classification of micro-scale biodigester sizing (i.e. define the minimum and maximum for micro-scale digester);
- Classification of all feedstock that should be utilised for all micro-scale biodigesters;
- Price guidelines which regulate the cost micro-scale biodigester installers should charge (i.e. tax exemption, subsidies and support aid to enable biogas utilisation);
- Biodigester quality (i.e. safety standards, lifespan warranties and guarantees);
- Certification/ accreditation of micro-scale biodigester installers;
- Compulsory biodigester maintenance through a certified/ accredited maintenance officer;
- Biogas slurry management and sorting (i.e. biogas fertilizer management utilization and pricing regulation);
- Awareness campaigns for rural communities;
- Penalties for non-compliance.

VI. CONCLUSION

A sustainable operational method for a micro-scale biodigester in South Africa was presented. The research further evaluated the cause of digester failure and proposed solutions for resolving these challenges. Lack of micro-scale biodigester policy was identified as a gap that needs to be resolved in order to stimulate the adoption of micro-scale biogas digesters. Overpricing presents micro-scale biodigesters as an unaffordable technology, as a result, clean energy sources have not been fully adopted in rural households. The few micro-scale biodigesters that have been installed in South Africa have set a bad precedence for the biogas technology. On the contrary, the lack of energy provision in rural areas continues to exclude the poor from participating meaningfully in the South African economy. Socio-economic benefits of micro-scale biogas digesters are understood and there is a great potential for creating jobs while combating climate change. However, there are no incentive programmes such as the Department of Trade and Industry's Manufacturing Competitiveness Enhancement Programme and Eskom rebate for small-scale renewables. The motivation for such incentives can be stimulated from numerous factors that promote universal energy access, climate change mitigation, job creation, and rural economy advancement and reduced health impacts related to adopting micro-scale biodigesters. Generally, there is a limited awareness of micro-scale biogas in South Africa. South Africa does lack a biogas strategy or policy which would regulate the micro-scale biogas sector, consequently, policy gaps and improvements have been recommended.

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