# Impact of PESTLE Constraints on the Development of Small-scale Biogas Technology in Sub-Saharan Africa: A Systematic Review

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## Abstract

The sustainable production and use of small-scale biogas energy is needed to ensure clean household energy access in developing countries including the Sub-Saharan Africa (SSA) region. This is influenced by market risks which can be identified as political, economic, social, technical, legal and environmental (PESTLE). This study examines peer-reviewed and grey literature for the period from 2000 to 2020 to identify the PESTLE constraints and assess their impact on the sustainable deployment of the technology in the SSA region. The production of biogas with small-scale plants is commonly by rural and peri-urban households. Results show that economic constraints are the most dominant and reducing at a slow pace. This is followed by political constraints which have received much attention in the last two decades. Despite the provided policy improvements, national bioenergy policies and interventions are still to make significant gains, especially in the Central African region. In order of significance, the Southern, East and West Africa regions have made comparably larger progress in reducing the constraints. However, to achieve sustainable development of the technology, there is need to further address the PESTLE constraints at national and regional level. This study partly deduces that the unsustainable production, use and inadequate regulation of the small-scale biogas sector is delaying its transition in the SSA region.


## Highlights

- The PESTLE constraints are identified.
- PESTLE constraints impact the adoption and diffusion of small-scale biogas technology in SSA.
- Sub-regions of SSA portray uneven constraints to the development of small-scale biogas technology.
- Mitigation of PESTLE impacts require complex solutions.

# 1. Introduction

Biogas technology is considered as a cost-effective method that can be used to reduce greenhouse gas (GHG) emissions from biomass or organic wastes, reducing deforestation, household air pollution and improving rural sanitation through appropriate waste management. Biogas is also a modern form of energy produced after anaerobic digestion or fermentation of various biomass materials (IRENA, 2017). As the world is mobilising for a transition to clean energy, it is essential to understand changes in the political, economic, social, technological, environmental and legal (PESTLE) factors affecting the development of small-scale biogas technology (BGT) in sub-Saharan Africa (SSA). Biogas technology needs to be researched, demonstrated, invested, implemented and diffused in Africa (Parawira, 2009). Between 1980 and 2000, only about 2400 biogas units were installed in Sub-Saharan Africa through donor and demonstration projects (Martinot et al., 2002). Karekezi et al. (2003) stated that the success of renewable energy technologies (RETs) in the SSA region was limited by a combination of factors which are institutional and infrastructural in nature; inadequate RET planning policies; lack of coordination and linkage in the RET programme; pricing distortions which are not advantageous to renewable energy; high capital investment costs; weak dissemination strategies; insufficient qualified manpower; insufficient baseline information; and, weak maintenance service and infrastructure. The current situation has evolved and will greatly impact the attainment of the sustainable development goals and the Agenda 2063 of the African Union, which aims by 2063 to develop efficient, reliable, affordable and environmentally friendly energy networks through development of clean power generation and development of renewable energy resources (including biogas).

The millennium development goals (MDGs) were among the initiatives established in 2000 to fight poverty in its many dimensions for 15 years. Biogas technology development was addressed by mainly MDG 7 (Ensure environmental sustainability) (United Nations, 2015). Since 2013, the United Nations initiated the SE4ALL (Sustainable Energy for All) initiative in connection with the 2030 Agenda for Sustainable Development. Specifically, the sustainable Development Goal (SDG) 7 emphasises the imperatives of achieving universal access to energy through increases in access to renewable or clean energy and the improved energy efficiency (UNDP, 2018). Three main approaches have been commonly used to deploy biogas technology. These include the holistic, life cycle and the market-oriented approaches. The holistic approach focuses on the acceptability and performance of the biogas plant. Emphasis of this approach is laid on the adjustment of the existing processes for management of solid waste, improvement in usage of biogas and manure and the addition of competing technologies. The life cycle approach aims at assessing the practicability of biogas projects to understand the critical feasibility components of the biogas interventions. Finally, the market-oriented approach focuses on the different stakeholders that are involved at the different levels of the value chain of the biogas project implementation. This approach has much been used by the fore promoters of biogas technology in the region including the SNV, Hivos and Heifer International.

According to Al (2011), small-scale biogas plants have played several roles in SSA, including the reduction of poverty, the supply of household (HH) energy, improved food production, improvement of sanitation, water and indoor air quality, carbon sequestration in soils, soil erosion, degradation and reduced deforestation. SSA makes up to 14.65% (December 2020) of the world's population. However, SSA has the lowest energy access rates in the world. In 2019, the proportions of SSA having access to electricity was 48% meanwhile clean cooking was lagging at 15%. This implies that up to 85% of the population still relied on inefficient, polluting and traditional cooking systems. Regarding small-scale biogas plants, the total number in 2012 had risen to nearly 23,000. By December 2018, the number rose to 75,561 with the involvement of other agencies under the Africa Biogas Partnership Programme (ABPP) (Freeman et al., 2019).

The development of small-scale BGT is a complex problem regarding the complex nature of the factors influencing it. For the efficient adoption and diffusion of the technology in the developing world, it is important to understand the interaction of the biogas system with other systems in order to provide appropriate interventions. In SSA, this technology consists of usually small-scale biogas digesters, mostly less than or equal to 10 cubic metres in volume and marred with several development constraints. These constraints affect the future development of the technology. From the market development point of view, this study aims at collecting the PESTLE constraints and analysing them to reveal the implications on the advancement of the technology in the region. The development of this technology requires an understanding of the constraints to provide mitigation measures. This study aims at analysing the PESTLE constraints influencing the development of this small-scale BGT in SSA. This study is also essential to understand the impact of PESTLE factors to reveal past lessons to give the best-fit recommendations for future development. A systematic approach has been applied to reveal the link between studies on biogas technology from 2000 to 2020 in the SSA region.

The PESTLE analysis is one of the strategic management tools that can be used to determine for a given project, service or product, the inherent potential or risk in relation to its integral surrounding (Zahari & Romli, 2019). It is used to identify the risks belonging to stated factors such as political, economic, social, technological, legal and environmental (Rastogi, 2016). The PESTLE analytical approach is relevant to understand the interaction of small-scale BGT and the SSA operation environment. Political and legal aspects underpin the enabling environment for the development of small-scale BGT. These factors establish the rights and assets of the stakeholders concerned. These factors are captured in policies, laws enacted by governments, regions and local communities influencing biogas technology development. The financial incentives contribute to attracting investors to biogas technology, including small-scale users. A robust, long-term institutional framework is also necessary to ensure the coordination and coherence of policies affecting energy, environment, and agricultural practices (Milbrandt & Uriarte, 2012). Technical factors affecting small-scale biogas technology include; the choice of biogas digesters, identification, availability of raw feedstuffs on a long-term basis and over the whole year, or supplies will be inconsistent, and people will lose confidence in the technology (WEC, 2004).The Clean Development Mechanism (CDM) can promote renewables projects in developing economies to offset emission reduction commitments with the Kyoto protocol in developed countries, which by investing in developing countries can earn credits (WEC, 2004).

## 2. Methodology

This study geographically covers the Sub-Saharan African region. The region comprises according to the United Nations of forty-nine (49) countries located in south of the Sahara Desert. A two-stage conceptual approach is applied to assess the impact of PESTLE constraints on the development of small-scale biogas technology in this region Firstly, a systematic review is performed to identify and categorise the PESTLE constraints. Secondly, an impact assessment of the constraints is performed to reveal the implications of the factors on the future development of the technology in the region. The review considered publications for the period from 2000 to 2020.

# 2.1. Systematic literature review

A systematic review of peer-reviewed and grey literature on small-scale biogas technology in Sub-Saharan Africa published from 2000 to 2020 was conducted. The political, economic, social, technological, legal and environmental constraints to the development of small-scale biogas technology were retrieved and categorised during the review. The following questions were investigated: What is the evolution of PESTLE factors affecting the development of small-scale biogas technology in Sub-Saharan Africa? How do the constraints affect the adoption and diffusion of small-scale BGPs in the region? What are the impacts of the constraints on the sustainable development of small-scale BGP? The search strategy consisted of a combination of keywords such as ‘sub-Saharan Africa biogas’ were searched using Mendeley Desktop Version 1.19.4 to identify peer-reviewed literature on small-scale biogas plants in Sub-Saharan Africa. This method collected titles and links of related articles from all sources on the world wide web. The titles of interest were collected, and the full articles were searched and downloaded from SCOPUS and Web of Science. Useful articles were stored on Mendeley Desktop Version 1.19.4. To identify the articles for specific countries, ‘Sub-Saharan Africa’ in the keyword above was replaced by the name of the country. Furthermore, ‘developing countries’ was used as part of the keyword to gather useful literature. This further helped in the collection of more articles and references. Grey literature was obtained from various search engines on the world wide web. The optimisation of search results was achieved with Boolean operators.

## 2.2. Study selection

To filter the previously selected and stored literature in Mendeley Desktop Version 1.19.4, keywords such as ‘biogas Africa’ were used to sort the most useful articles. Then, more keywords like ‘political, economic, social, technology, environment, legal, adoption, dissemination and diffusion were used to describe the development of small-scale biogas technology in SSA. These words were used to sort and select the literature in the latter software. Finally, the rest of the literature not containing these keywords were used to obtain more information to substantiate the direct information previously collected. Figure 1 shows the stage stages of the selection of articles.

**Figure 1**: Stages of the selection of publications for the study

## 2.3. Inclusion and exclusion criteria

We read and assessed all the studies collected. The agreed-upon inclusion criteria were:

- studies focused on small-scale biogas technology in Africa and developing countries
- constraints to adoption and widespread dissemination or diffusion
- prospects of small-scale biogas plants in SSA

We excluded studies that dealt with large scale or commercial plants. The exclusion is performed assuming that commercial biogas digesters are technically and economically better designed, constructed and managed than the small-scale biogas plants. Again, from the year 2000 to 2020, more of small-scale BGPs have been disseminated as a means of alleviating poverty and hunger in SSA. Hence the focus on the small-scale digesters.

## 2.4. Data extraction

In handling the literature, they were sorted by year of publication in Mendeley Desktop Version 1.19.4, and the data were extracted systematically. The constraints were extracted from the eligible studies and categorised into political, economic, social, technological, legal and environmental. The year of publication (from 2000 to 2020) and the geographical boundary of the study (country, region or developing countries).

The PESTLE data collected was arranged in a PESTLE table prepared in Microsoft Excel. Similar information pertaining to a given PESTLE aspect were discussed, and a common best-fit description or analysis was adopted.

# 2.5. Data analysis

The analytical technique used for this study was the PESTLE approach. Some of the PESTLE indicators shown in Fig. 2 were retrieved from both peer-reviewed and grey literature. Manual search and reading were done to identify the key constraints and risks related to the development of small-scale biogas technology in SSA. For each of the PESTLE factors, the strengths/opportunities and the weaknesses/threats are identified. After the analysis, key recommendations were then proposed to re-orientate the sustainable development of the technology in the region.

The impact of the PESTLE factors on the development of the small-scale biogas technology was based on the adoption and diffusion of the BGPs. Based on the categorisation of the PESTLE constraints, a ranking of the constraints was performed for the sub-regions of SSA including the East, West, Southern and Central Africa. Weighting factors were used to represent the severity of the constraint in each sub-region. The more frequent the identified constraints, the higher the weighting factor and vice versa.

## 3. Results And Discussions

# 3.1. Search results

From the literature search, a total of 11,361 publications were obtained. 11,317 publications were peer-reviewed articles, while 44 were grey literature gotten from various search engines of the World Wide Web. After screening the publications in two stages, 64 publications were selected based on their focus on the small-scale biogas plants in SSA or developing countries and the availability of PESTLE information in them. Out of these 64 publications, 58 were peer reviewed and 6 were grey. The distribution of the publications studied is shown in Table 1.

Table 1
Summary of the articles collected from the literature search

| Geographical zone/ Country | Reference (s) | Σ |
|---|---|---|
| Africa, SSA | So et al. (2020), Surroop et al. (2019), Griffith-Jones et al. (2012), Roopnarain & Adeleke (2017a), Mandelli et al. (2014), Bamikole Amigun et al. (2011), Verbist (2018), Mulinda et al. (2013), Roopnarain & Adeleke (2017b) Kinyua et al. (2016), Cheng et al. (2014), Surendra et al. (2014), Maes & Verbist (2012), Ruane et al. (2010), Pollmann et al. (2014), Rupf et al. (2016), Smith et al. (2015), Rupf et al. (2015), Mwirigi et al. (2014b), Mohammed et al., (2013), Parawira (2009), Gebreegziabher et al. (2014), Mwirigi et al. (2014), Nevzorova & Kutcherov (2019), Terrapon-Pfaff et al. (2018), Amigun & Blottnitz (2009) | 26 |
| East Africa | Walekhwa et al. (2009), Wassie & Adaramola (2019) Karanja & Gasparatos (2019), Mwirigi et al. (2009), Kamp & Forn (2016), Mengistu et al. (2015b), Kamp & Forn (2015), Sarakikya (2015), Mwakaje (2008), Omer (2005), Godfrey (2012), (Wilson, 2007) | 12 |
| Central Africa | Muh et al. (2018), Tangka et al. (2016), Kimengsi (2015), Balgah et al. (2018) | 4 |
| Southern Africa | Walwyn & Brent (2015), Boyd (2012), Msibi & Kornelius (2017), Rasimphi & Tinarwo (2020), Chirambo (2016), Aliyu et al. (2018), Shane et al. (2017), Shane et al. (2016), Jingura et al. (2013), Mokhtar, et al. (2013), Kemausuor et al. (2011), Painuly & Fenhann (2002) | 12 |
| West Africa | Aliyu et al. (2015), Ishola et al. (2013), Akinbami et al. (2001), Okello et al. (2013), Mas'ud et al. (2015), Ohimain (2013), Ituen et al. (2009), Adeoti et al. (2000), Osei-Marfo et al. (2018), Kemausuor et al. (2015). | 10 |
| Total | | 64 |

Countries of the region where national biogas programmes were implemented, produced documents containing useful information needed to understand changes in the small-scale biogas technology. Unfortunately, academic publications were not found for the following countries: Cape Verde, Mauritania, Togo, Central African Republic, Equatorial Guinea, Sao Tomé and Principe, Liberia, Gambia, Benin, Mali, Togo, Senegal. However, a variety of grey literature on these countries was found.

## 3.2. PESTLE constraints to the development of small-scale biogas technology in SSA

Despite the market penetration of renewables in SSA, small-scale biogas technology remains one of the least exploited regarding the available potential. Barriers to their enhanced development are at all levels - in practical policy attitudes, economic sphere, social, technology management, environment and legislation. The results of the PESTLE factors are presented below.

### 3.2.1. Political

Political constraints to the development of small-scale BGT are still evident. Small-scale biogas technology still has minor influence on national energy supplies in SSA. SSA is still faced with several bottlenecks regarding the considerations of small-scale BGT issues related to the planning and implementation of bioenergy interventions. Before the year 2000, no SSA country had a bioenergy policy. Despite the advances made by some countries in the development of renewable and/or bioenergy policies, political support concerning policy frameworks that strongly support small-scale BGT development is inadequate. Austin (2003) indicated that South Africa could learn lessons from the Indian, Chinese and Nepalese programmes, with offers already having been made of bilateral governmental assistance in setting up such a programme. In 2009, (Parawira, 2009) still identified that poorly informed and uninformed authorities and policymakers in SSA have led to gaps in the formulation of renewable energy policies. As part of the experimentation process, SNV, Heifer International and Hivos assisted national governments of the region to develop and implement biogas programmes. However, the harmonisation of the policies. The African bioenergy policy framework and guidelines exist since 2013 (AUC-ECA, 2013). However, countries are still in the process of preparing or are still to begin the preparation of this policy. The passivity of some governments still remains a threat to promote the new biogas technology (Pollmann et al., 2014). In 2017, bioenergy provided 176,000 jobs in the region. Biogas technology expansion opens employment opportunities for masons, plumbers, civil engineers, and agronomists (Mengistu et al., 2015). However, the number or percentage of these jobs created has not been realistically determined yet. There is increasing priority to biogas technology in 2020 compared to the year 2000. Bottom-up approaches are required for the significant inclusion of small-scale technology in the national renewable energy policies. Most development policy frameworks in the region have no direct strategy for the development of small-scale biogas technology. The stability of political framework and transparency is therefore required for the development of small-scale biogas technology. Socio-political instability in some SSA countries has led to the low adoption rate and dissemination of small-scale biogas plants. For example, Burundi was affected by the war between 1993 and 2000 (SE4All, 2013). Since then, they are still reconstructing the country and pending significant interest in developing small-scale biogas plants. Under a stable socio-political situation, the biogas potential is an asset.

### 3.2.2. Economic

The primary economic constraint to the development of the small-scale BGT is the inadequate investment cost. The average cost of small-scale biogas plants in some SSA countries is shown in Table 2. However, the cost of the technology is mainly dependent of the plant's geographical location (Amigun & Von Blottnitz, 2010). Boyd (2012) reported in South Africa inadequate access to finance. Generally, there is still a inadequate reliable information on the benefits of the technology by financial institutions (Parawira, 2009) in the region and a lack of financing structures for small projects. The revenue from the digested slurry, otherwise referred to as organic fertiliser, is largely not yet estimated for most SSA countries. There is also an information deficit on the economic viability of available biomass and waste resources (So et al., 2020). Due to clustering of poor or average homes in some countries, construction space is seen as a constraint to the adoption of the small-scale BGPs. This was identified in the case of Nigeria by Akinbami et al. (2001). Mwirigi et al. (2014), in a study in Uganda, stated that other factors affecting the adoption of small-scale biogas technology include low levels of awareness of the potential uses of biogas and the small size of landholdings, which limits the number of different types of land use unless the uses are complementary. However, by 2017, Kenya had made the most progress toward establishing viable biogas plant markets, including hosting companies with prefabricated digesters and establishing 22 marketing hubs, linking rural institutions to local enterprises and finance (Clemens et al., 2018). Makai & Molinas (2013) revealed that the payback period of small-scale BGPs in Zambia is 3.25 to 3.75 years. According to Kabyanga et al. (2018), many of the biogas designs promoted in Uganda have proved to be too expensive for the average Ugandan to afford. They added that a cheaper flexible balloon digester is being proposed, but there has been no evidence on this design's economic viability. Generally, small-scale biogas users still find it challenging to afford the complete installation of the small-scale BGPs. Parawira (2009) recommended the need to provide loans and subsidies to encourage and promote biogas technology. Market incentives for biogas technology take the form of 'soft' loans, direct and indirect subsidies and international funding schemes through the Clean Development Mechanism fund and Joint Implementation Programme' (Surroop et al., 2019). In several OECD (Organization for Economic Cooperation and Development) countries, firms and individual households can collect government subsidies if they adopted technologies that have socially desirable characteristics (Mengistu et al., 2015b).

Table 2
Average costs of small-scale biogas plants in some SSA countries

| Location | Capacity ($m^3$) | Year constructed | Cost (US$) | Source |
|---|---|---|---|---|
| Burkina Faso | 6 | 2004 | 1,209.00 | Osei-Marfo et al. (2018) |
| Ghana | 6 | 2004 | 1,358.00 | Osei-Marfo et al. (2018) |
| Ghana | 6 | 2011 | 2,189.00 | Osei-Marfo et al. (2018) |
| Ghana | 6 | 2015 | 851.00 | Osei-Marfo et al. (2018) |
| Ghana | 10 | 2011 | 3,169.00 | Osei-Marfo et al. (2018) |
| Kenya | 8 | 2004 | 2,973.00 | Osei-Marfo et al. (2018) |
| Uganda | 6 | 2004 | 1,005.00 | Osei-Marfo et al. (2018) |
| Rwanda | 6 | 2007 | 859.00 | Amigun & Blottnitz (2010) |
| South Africa | 6 | 2007 | 1149.86 | Amigun & Blottnitz (2010) |

Akinbami et al. (2001) recommended that using local materials reduce construction costs, which constituted up to 65% of the total costs. Labour and other costs amounted to an additional 35% of the cost (Akinbami et al., 2001). In some cases, household labour was used to reduce costs (Osei-Marfo et al., 2018).

Biogas technology has been scaled up in SSA during the last two decades with programme funds mainly from SNV, Hivos and Heifer International. However, the sustainability of the adoptions is not ensured because of the various constraints after the programmes. One possible, despite the controversial approach to increasing the adoption of small-scale biogas technology out of the programme funds is to utilise the available funds that a household possesses, rather than targeting the very poor households (Smith et al., 2011). Information dissemination on the successful implementation of the technology by farmers to their counterparts proves to be the best tool to promote biogas use (Berhe et al., 2017). Biogas produced with small-scale digesters is used in different appliances including biogas stoves (one and two burners), water heater (Mwirigi et al. (2014a), biogas lamp (Khandelwal, 2009; Mwirigi et al., 2014a) and biogas electricity generator (Tangka et al., 2016; Mwirigi et al., 2014a).

### 3.2.3. Social

In the beginning of the year 2000, socio-cultural constraints still impacted the uptake and dissemination of the small-scale BGPs. In Nigeria, Akinbami et al, (2001) reported that the inertia toward changes, especially when it involves an unfamiliar (even though simple) technology, are potential barriers to adopting and disseminating biogas technology. Walekhwa et al. (2009) later in Uganda assessed Uganda's acceptance of small-scale BGT and discovered that the development and acceptance of biogas technology largely depended on exploiting its technological opportunities over the existing technologies. This was exacerbated by the poor ownership responsibility of the users (Parawira, 2009). In Rwanda, Tanzania and Malawi, (Barry et al., 2011) identified that training and skills development of communities would alleviate the lack of user acceptance. There was the need to improve the skills base of the community to help maintain the technology. The dissemination needs to be done through capacity building, governance and integrated development (Ghimire, 2013a). In 2014, low levels of awareness of the potential uses of biogas and the small size of landholdings, limiting the number of different types of land use unless the uses are complimentary (Mwirigi et al., 2014). In Uganda, an increase in age and level of education were inversely related to adoption. In contrast, the availability of traditional fuels and the increase in household size positively impacted the acceptance of the technology (Mwirigi et al., 2014). The low levels of education and income of women were the leading causes of limited, little or no involvement of in the decision for procurement of the BGPs. The decision to install the BGPs was mainly made by the male heads of households who control resources and their allocation (Mwirigi et al., 2014). Over the past two decades, biogas stakeholders have made significant efforts to create awareness on the role of small-scale BGT. In the region, the technology is generally accepted by people of different socio-cultural and religious backgrounds. But affordability and gender constraints still need to be addressed for wider adoption of the technology. Notwithstanding, Nevzorova & Kutcherov (2019) still identified a lack of acceptance as one of the constraints to the development of small-scale BGT in SSA. A study by (Lemma et al., 2020) in southern Ethiopia also showed that in households, 92.5% of biogas users and 77.5% of non-users tend to have a positive attitude towards biogas technology. However, 52.5% of the non-users did not have adequate information, while the installation costs deterred 25% of the non-users.

### 3.2.4. Technological

*Technical potential of small-scale BGPs in SSA*

The technical potential is defined as the number of households that can meet the two basic requirements – sufficient availability of both dung and water – to operate a biogas plant (SNV, 2018). The first estimation of the technical potential of domestic or household biogas in Africa was done in 2007 by Heegde & Sonder (2007). Two leading indicators were used included the number of households with access to water and the number of domestic cattle per household (ibid). The small-scale biogas potential of SSA is continuously being assessed. A study by SNV (2018) showed that the present technical potential for household biogas plants in Africa arrives at 32.9 million installations. By 2012, the total number of BGPs had risen to nearly 23,000, by December 2018, to 75,561 with the involvement of other agencies under the umbrella of the Africa Biogas Partnership Programme (ABPP) (Freeman et al., 2019). This shows that SSA has exploited less than 1 per cent of its technical biogas potential. Figure 3 shows the quintile distribution of the technical potential of HH biogas plants in SSA.

Source: Data from SNV (2018).

*Choice of digester design*

There exist three main philosophies commonly applied in the design of household or small-scale BGPs, namely the floating drum, the fixed dome, and the flexible balloon digester (Jansen & Rutz, 2012). Prefabricated biogas digesters following the above philosophies are also present in the region (Cheng et al., 2014). Biogas plants' size is be based upon: (i) the (daily) amount of available feeding material; and (ii) the biogas requirement of the family (Freeman et al., 2019). Some of the major constraints identified include the wrong selection of the design and size of the digester. This contributes to the operation failure in some cases. Construction of the digesters with low quality materials has resulted in short life, low efficiency biogas plants.

Table 3
Types of digesters

| Type of digester | Advantages | Disadvantages | Source |
| --- | --- | --- | --- |
| Fixed dome digester | • eliminates the use of costly mild steel gasholder,<br>• relatively low installation cost (about two-thirds of the cost of the floating drum digester),<br>• does not have moving parts,<br>• does not have rusting steel parts,<br>• long lifespan (20 years or more),<br>• possible underground construction,<br>• saves space,<br>• creates local employment during construction, | • digesters are usually not gastight (porosity and cracks). The gas tightness is a problem that pertains only to the constructed systems and not prefabricated systems,<br>• gas pressure fluctuates substantially. | (Mulinda et al., 2013). (Jansen & Rutz, 2012). |
| Floating drum | • has a simple operation design,<br>• operates at constant gas pressure, and the volume of stored gas is visible directly on the | • high installation cost (up to 50% greater than that of a fixed dome digester),<br>• uses many steel parts that can easily corrode, leading to short lifespan (up to 15 years; in tropical regions and about 5 years for the drum),<br>• requires regular maintenance costs due to painting. | (Mulinda et al., 2013), (Jansen & Rutz, 2012). |
| Flexible balloon biogas digester | • technically cheapest and simple design to install<br>• easy transportation,<br>• shallow construction<br>• high digester temperatures,<br>• easy cleaning, emptying, and maintenance. | • short lifespan (about 5 years),<br>• High risk of damage,<br>• no real local employment creation, little scope for self-help<br>• low gas storage is a limitation | (Kabyanga et al., 2018), (Jansen & Rutz, 2012) |

Since the first introduction of the small-scale technology in SSA, the conventional fixed dome and floating biogas digester were promoted. The fixed-dome design is accepted by most users as the most viable design that is affordable and reliable for the domestic market. In SSA like other parts of the world like India, the switch from the floating drum design to the fixed dome design is increasing (Jansen & Rutz, 2012). However, due to inadequate finance to purchase these plants, the private sector has developed low-cost biogas plants, including the Flexi-biogas in Kenya, while others have recycled plastic containers into biogas digesters. From 2011 to 2014, IFAD and Biogas International distributed 500 Flexi-Biogas System (FBS) units to rural Kenyan households (Sovacool et al., 2015). However, the flexible balloon biogas digester design is not suitable for a programme-based approach to digester installations where a predefined financing scheme (including subsidies linked to quality assurance measures and long-term production of voluntary or certified emissions reductions). Therefore, long-term functionality, is needed. Balloon BGPs are preferable wherever the balloon surface is not exposed or has the likely risk of damage especially in areas where the temperature is constant high (Jansen & Rutz, 2012).

*Anaerobic digestion efficiency*

Biogas production through anaerobic digestion of organic waste using small-scale BGPs is a continuous learning process in the regions. Parawira (2009) in Uganda identified that household biogas digesters in SSA, usually lack facilities to remove sand, stones and other non-digestible materials, which accumulate over years of use, thereby decreasing the volume of the digesters and hence reduce efficiency. SSA has favourable conditions for biogas technology, namely a suitable tropical climate in most parts of the region (Rupf et al., 2015). From the poor designs to poor operation and maintenance, followed by the lack of inadequate monitoring devices, most of the small-scale BGPs rely on the local climatic conditions. To realise the full potential of biogas, the efficiency of end-use appliances must also be improved and adapted to local cooking conditions, as has been done with other cooking technologies (Freeman et al., 2019). Co-digestion has also proven to ease or improve biogas, e.g. the case of a mixture of poultry/cow dung/water hyacinth at the Songhai Farm in Burkina Faso.

*Waste availability*

In SSA, the feedstock for biogas production is mainly excreta from livestock, e.g. cattle, sheep, goats, horses, donkeys, rabbits and chickens, but also from humans if culturally acceptable (Orskov et al., 2014). The biogas potentials of the available animal and agricultural feedstocks have not been thoroughly researched. Karekezi et al. (2003) stated that despite the proof of the viability of small-scale biogas plants, dung collection proved more problematic than anticipated, particularly for farmers who did not keep their livestock penned in one location. More R&D is also needed to explore better substrates to boost the efficiency and performance of the biogas plants. Land management and the method of rearing is also affecting the availability of feedstocks. For example, the results of the nationally representative household surveys in Ethiopia, Kenya, Rwanda, Mozambique and Zambia, concluded that farm sizes in Africa are declining over time, with approximately 25% of agricultural households being virtually landless, controlling less than 0.1 ha $caput^{-1}$, the largest part of the variation in farm sizes occurring within, rather than between villages. Households controlling such a low area of land may be limited in the livestock they can manage, which may, in turn, limit their potential to run a biogas digester (Orskov et al., 2014).

*Water availability for anaerobic digestion across the region*

Mwirigi et al. (2014) identified hurdles to the wider adoption of small-scale BGT in SSA, including limited access to water. In South Africa, Calendar et al. (2007) revealed a common misperception that access to water is a constraint on the use of BGT at the household level. Since each family uses water every day, this same water can easily be directed to the biogas digester. According to Griffith-Jones et al. (2012), households in SSA were 28.2% and 125.2% more likely to have access to improved water sources in 2000–2005 and 2010–2015, respectively, than in 1990–1995. The World Bank (2020) reports that 27% of the population of SSA have access to safely managed drinking water.

*Design, construction and maintenance*

In SSA, inexperienced technicians and consultants have resulted in poor quality BGPs. This is a result of poor selection of construction materials (Parawira, 2009). This is also due to inadequate technical know-how in the design and construction of small-scale biogas plants (So et al., 2020) and flawed or wrong operation and maintenance culture (So et al., 2020). The optimisation of the BGP design process has been constrained by inadequate knowledge, even at the level of research institutes and universities (Parawira, 2009). A study by Berhe et al. (2017) in Ethiopia's Tigray region showed that 58.1% (of a total of 3600 BGPs) of the installed BGPs were non-operational due to incomplete installation, other technical problems, and limited supervision. Waste collection reliability is still not measured. However, the small-scale biogas plants have contributed to reducing the time to collect fuelwood by women and children in the region.

### 3.2.5. Legal

Several disputes persist in Sub-Saharan Africa regarding the sustainable management of local water, land and agricultural wastes for small-scale biogas production. In South Africa, Du Plessis (2003) identified that no legal measures were dealing with the collection of dung, except in the case of the Gas Act of 2002 that excludes small biogas projects in rural communities from the Act. Some countries in sub-Saharan Africa have relatively successfully scaled up renewable energy through changing energy market structures and introduced incentives (Griffith-Jones et al., 2012). South Africa and Uganda are some of the identified SSA countries that have instituted Renewable Feed-in Tariffs (REFIT) on renewable energy, including biogas technology. According to private finance practitioners, Griffith-Jones et al. (2012) added that a FIT of 50% is a powerful incentive mechanism for renewable energy deployment in developing countries. In Kenya, biogas equipment such as stoves, other appliances, and prefabricated digesters may be exempted from import tax. Notwithstanding, interviews with biogas stakeholders (mainly entrepreneurs) indicate that the exemption can only apply to the entire shipping containers of appliances and therefore, do not benefit small enterprises. Moreover, the process to obtain duty-free status is unclear to local entrepreneurs in the region. No tax exemptions exists in Tanzania and Uganda (Clemens et al., 2018), as well as on most other countries of the region. According to IRENA (2018), renewable energy auctions can be successfully implemented in South Africa, Uganda and Zambia. However, only large-scale biogas technology producing marketable electricity can benefit from these auctions. However, small-scale biogas technology still lacks cost legal frameworks for development incentives in the region.

### 3.2.6. Environmental

The BGPs in SSA are multi-functional depending on the reason for construction such as sanitation, energy recovery, management of waste and environmental protection (Mulinda et al., 2013). The unsustainable use of fuelwood biomass can accelerate deforestation and lead to soil erosion, desertification and an increased risk of flooding and biodiversity loss (Parawira, 2009). The Clean Development Mechanism (CDM) can promote renewables projects in developing countries to offset emission reduction commitments under the Kyoto protocol in developed countries, which by investing in developing countries can earn credits (WEC, 2004). Venkata et al. (2015), per 2010 data, indicated that household air pollution mortality and morbidity led to 14% of the deaths in SSA in an affected population of 3.5 million. This also led to 24% Disability-Adjusted Life Year (DALY). In Ethiopia, each household BGP has the potential to reduce about 6024 kg $CO^2$e per year of GHG emissions (Lemma et al., 2020). Under the Paris Agreement on Climate Change, all SSA countries have included renewable energy actions (covering all technologies and end-use applications) as commitments to tackle climate change as well as spur economic growth (UNECA, 2018). Despite the ratification agreement by all SSA countries, there is an inadequate effort being made by governments to develop small-scale biogas plants as part of the national environmental strategies.

## 4. Impact Of Pestle Constraints

Based on the ranking of the different PESTLE constraints, the economic constraints are the most dominant, especially in the Central African sub-region as shown in Fig. 4. This implies that the development of the technology is more economically constrained in this region, relative to the other sub-regions. Geographical changes can be observed regarding the economic access to the technology. The Southern Africa sub-region has visibly reduced the economic constraints than any other region in the SSA region. Affordability of the small-scale BGPs is the least in East Africa and highest in Southern Africa. Most of the users of small-scale BGPs in the region are rural dwellers depending on but not limited to the household income to fund the small-scale biogas projects. Owners of agricultural and livestock farms are more likely to afford and sustain the technology. Incentives are still needed from private, public and international institutions or organisations in financing this technology for the resource poor households. The implementation of climate change agreements on the reduction of GHG emissions remain potential source of funding for the local biogas project. A turn useful action would be the development of context-based business models and more job creation that recognises the key sustainability issues of the technology. Political constraints have greatly reduced due to the willingness of the public and partner organisations to develop the technology. The absence of bioenergy policies in some countries is still constraining the development of the technology. The gaps in bioenergy policy can be filled by elaborating new policies or updating existing ones based on the changes at the different development levels – micro, regime and landscape (directly addressing issues related to biogas technology, especially in rural areas). The appropriateness of the policy instrument needs to be the focus of the process in order to address specific rural, country or regional specificities. The African bioenergy policy framework and guidelines exist since 2013 (AUC-ECA, 2013). This policy document provides the key aspects that should be included in bioenergy policies. However, the current state of country bioenergy elaboration is not well known due to inadequate tracking of progress data. The central African sub-region is still lagging in relation to the other regions in reducing policy constraints. This can justify the low the uptake and dissemination in the sub-region. Regarding social impacts, inadequate awareness and gender mainstreaming in biogas projects across the region has reduced the social impacts of the technology. Guidance on gender mainstreaming in small-scale biogas projects in the region was only elaborated in 2010 using Kenya as the case study (Energia and Hivos, 2010). At about 11 years later, the region is still to make strides regarding this issue. Due to slow policy changes, access and control of land has limited women's control over the technology. Future interventions in small-scale biogas technology dissemination require national and regional strategies to increase the significant involvement of all genders in the development process. Technical constraints have exerted a significant influence on the efficiency, reliability and operation of the BGPs with variable inputs. This has been caused in part by the lack of quality standards in the design, construction, operation and maintenance of the BGPs. The role of research and development is indispensable to reduce these defects. Legal issues including standards and regulations, where addressed reduce the institutional burden on the adopters. These are more and more needed increase users' willingness and engagement in developing the technology. Due to the inability of the technology meet household energy needs, especially for cooking, there has been deforestation and indoor pollution (with devastating health consequences) have persisted.

## 5. Conclusion And Policy Implications

Despite the introduction of biogas technology in SSA in the mid-20th century, it is still seen as "young", considering the reforms still needed to boost its adoption and dissemination. The development of small-scale biogas technology in SSA is greatly influenced by political, economic, social, technological, legal and environmental aspects. In addition, institutional and geo-spatial factors greatly influence this technology. Political and economic inadequacies are negatively affecting the adoption and diffusion of SSA. However, social acceptance has improved in the past two decades, and socio-cultural barriers are reducing. Nevertheless, the development of small-scale biogas technology in SSA still requires appropriate technological innovation to increase the efficiency, reliability and performance of the small-scale biogas plants. Over the past two decades, civil society organisations, including SNV, Hivos and Heifer International have been the main promoters of the technology in SSA. This has been done through programme budgets which seem to lack follow up and sustainability of the implemented actions. The ABPP is currently fostering some of the actions of the later organisations and partners. Various governments of the region express a sense of ownership of the technology. However, the PESTLE inadequacies still require many governmental and CSO responses to boost the adoption and dissemination of the technology in the region.

## Abbreviations

| | | | |
|---|---|---|---|
| ABPP | Africa Biogas Partnership Programme | IRENA | International Renewable Energy Agency |
| BGP | Biogas plant | PESTLE | Political, economic, social, technological, legal, environmental |
| BGT | Biogas technology | REFIT | Renewable Energy Feed-in Tariff |
| CDM | Clean Development Mechanism | RET | Renewable energy technology |
| CSO | Civil Society Organisation | SDG | Sustainable Development Goal |
| GHG | Greenhouse gas | SE4ALL | Sustainable Energy for All |
| ha | hectare | SNV | The Netherlands Development Organization |
| HH | Household | SSA | Sub-Saharan Africa |
| IFAD | International Fund for Agricultural Development | UNDP | United Nations Development Programme |

# Declarations

**Author Contributions:** All authors conceived the idea for the paper. Chama Theodore Ketuama identified relevant literature, analysed the data and wrote the original manuscript. Revisions were done by Chama Theodore Ketuama, Jana Mazancová and Hynek Roubík. Supervision was done by Hynek Roubík.

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# References

1. Adeoti O, Ilori MO, Oyebisi TO, Adekoya LO (2000) Engineering design and economic evaluation of a family-sized biogas project in Nigeria. *Technovation*. https://doi.org/10.1016/S0166-4972(99)00105-4
2. Akinbami J-F, Ilori M, ., Oyebisi T, ., Akinwumi I, Adeoti O (2001) Biogas energy use in Nigeria: current status, future prospects and policy implications. Renew Sustain Energy Rev 5(1):97–112. https://doi.org/10.1016/S1364-0321(00)00005-8

3. Al S (2011) DFID Interdisciplinary Expert Workshop on the Potential of Small-Scale Biogas Digesters in Sub-Saharan Africa -. *Current*, 16–18
4. Aliyu AK, Modu B, Tan CW (2018) A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, *81*(June 2017), 2502–2518. https://doi.org/10.1016/j.rser.2017.06.055
5. Aliyu AS, Dada JO, Adam IK (2015) Current status and future prospects of renewable energy in Nigeria. Renew Sustain Energy Rev 48:336–346. https://doi.org/10.1016/j.rser.2015.03.098
6. Amigun B, Von Blottnitz H (2009) Capital cost prediction for biogas installations in Africa: Lang factor approach. Environ Progress Sustainable Energy. https://doi.org/10.1002/ep.10341
7. Amigun B, Von Blottnitz H (2010) Capacity-cost and location-cost analyses for biogas plants in Africa. Resour Conserv Recycl 55(1):63–73. https://doi.org/10.1016/j.resconrec.2010.07.004
8. Amigun B, Musango JK, Stafford W (2011) Biofuels and sustainability in Africa. Renew Sustain Energy Rev 15(2):1360–1372. https://doi.org/10.1016/j.rser.2010.10.015
9. Austin G (2003) Biogas energy and sanitation provision in South Africa. ESI Africa
10. Balgah RA, Mbue IN, Ngwa KA (2018) *The impacts of renewable energy on livelihoods: A case study of biogas adoption in Cameroon*. 7:220–2391
11. Barry ML, Steyn H, Brent A (2011) Selection of renewable energy technologies for Africa: Eight case studies in Rwanda, Tanzania and Malawi. Renewable Energy 36(11):2845–2852. https://doi.org/10.1016/j.renene.2011.04.016
12. Berhe TG, Tesfahuney RG, Desta GA, Mekonnen LS (2017) Biogas Plant Distribution for Rural Household Sustainable Energy Supply in Africa. Energy and Policy Research 4(1):10–20. https://doi.org/10.1080/23815639.2017.1280432
13. Boyd A (2012) Informing international UNFCCC technology mechanisms from the ground up: Using biogas technology in South Africa as a case study to evaluate the usefulness of potential elements of an international technology agreement in the UNFCCC negotiations process. Energy Policy 51:301–311. https://doi.org/10.1016/j.enpol.2012.08.020
14. Calendar E, Rates E, Us A, Us C (2007) *Biogas energy and sanitation provision in South Africa Biogas energy and sanitation provision in South Africa By Greg Austin, Director, Biogas Technology Africa Biogas energy and sanitation provision in South Africa*. *November 2000*, 2000–2002
15. Cheng S, Li Z, Mang HP, Huba EM, Gao R, Wang X (2014) Development and application of prefabricated biogas digesters in developing countries. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2014.03.035
16. Chirambo D (2016) Addressing the renewable energy financing gap in Africa to promote universal energy access: Integrated renewable energy financing in Malawi. Renew Sustain Energy Rev 62:793–803. https://doi.org/10.1016/j.rser.2016.05.046
17. Clemens H, Bailis R, Nyambane A, Ndung V (2018) Energy for Sustainable Development Africa Biogas Partnership Programme: A review of clean cooking implementation through market development in East Africa. Energy Sustain Dev 46:23–31. https://doi.org/10.1016/j.esd.2018.05.012

18. Du Plessis W (2003) Energy law and environmental protection in South Africa. Sustainable World 7:103–112
19. Freeman KK, Seppala JAK (2019) The power of dung Lessons learned from. World Bank Group Agriculture
20. Gebreegziabher Z, Naik L, Melamu R, Balana BB (2014) Prospects and challenges for urban application of biogas installations in Sub-Saharan Africa. Biomass Bioenergy 70:130–140. https://doi.org/10.1016/j.biombioe.2014.02.036
21. Ghimire PC (2013) SNV supported domestic biogas programmes in Asia and Africa. Renewable Energy. https://doi.org/10.1016/j.renene.2012.01.058
22. Godfrey A (2012) Dairy Farming and the Stagnated Biogas Use in Rungwe District, Tanzania: An Investigation of the Constraining Factors. In *Biogas*. https://doi.org/10.5772/32012
23. Griffith-Jones S, Ocampo JA, Spratt S (2012) *Financing renewable energy in developing countries: Drivers and bariers for sub-Saharan Africa*. *February*, 1–55. http://www.unepfi.org/fileadmin/documents/Financing_Renewable_Energy_in_subSaharan_Africa.pdf
24. IRENA (2017) Biogas for domestic cooking. A technonology brief. International Renewable Energy Agency, Abu Dhabi
25. IRENA (2018) Renewable energy auctions: Cases from sub-Saharan Africa. In */publications/2018/Apr/Renewable*-energy-auctions-Cases-from-sub-Saharan-*Africa*. http://irena.org/publications/2018/Apr/Renewable-energy-auctions-Cases-from-sub-Saharan-Africa
26. Ishola MM, Brandberg T, Sanni SA, Taherzadeh MJ (2013) Biofuels in Nigeria: A critical and strategic evaluation. In *Renewable Energy*. https://doi.org/10.1016/j.renene.2012.12.021
27. Ituen EE, John NM, Bassey BE (2009) Biogas production from organic waste in Akwa Ibom State of Nigeria. *Appropriate Technologies for Environmental Protection in the Developing World - Selected Papers from ERTEP 2007*. https://doi.org/10.1007/978-1-4020-9139-1_11
28. Jingura RM, Musademba D, Kamusoko R (2013) A review of the state of biomass energy technologies in Zimbabwe. Renew Sustain Energy Rev 26:652–659. https://doi.org/10.1016/j.rser.2013.05.036
29. Kabyanga M, Balana BB, Mugisha J, Walekhwa PN, Smith J, Glenk K (2018) Economic potential of flexible balloon biogas digester among smallholder farmers: A case study from Uganda. Renewable Energy 120:392–400. https://doi.org/10.1016/j.renene.2017.12.103
30. Kamp LM, Bermúdez Forn E (2016) Ethiopia's emerging domestic biogas sector: Current status, bottlenecks and drivers. Renew Sustain Energy Rev 60:475–488. https://doi.org/10.1016/j.rser.2016.01.068
31. Kamp LM, Forn EB (2015) Bottlenecks and drivers in Ethiopia's domestic biogas sector. *IAMOT 2015–24th International Association for Management of Technology Conference: Technology, Innovation and Management for Sustainable Growth, Proceedings*
32. Karanja A, Gasparatos A (2019) Adoption and impacts of clean bioenergy cookstoves in Kenya. *Renewable and Sustainable Energy Reviews*, *102*(December 2018), 285–306. https://doi.org/10.1016/j.rser.2018.12.006

33. Karekezi S, Kithyoma W, Initiative E (2003) Renewable energy development. *Workshop on African Energy Experts on Operationalising the NEPAD Energy Initiative, June*, 2–4
34. Kemausuor F, Addo A, Darkwah L (2015) Technical and Socioeconomic Potential of Biogas from Cassava Waste in Ghana. Biotechnol Res Int. https://doi.org/10.1155/2015/828576
35. Kemausuor F, Obeng GY, Brew-Hammond A, Duker A (2011) A review of trends, policies and plans for increasing energy access in Ghana. Renew Sustain Energy Rev 15(9):5143–5154. https://doi.org/10.1016/j.rser.2011.07.041
36. Khandelwal KC (2009) & G. V. K. Popular Summary of the Test Reports on Biogas Stoves and Lamps prepared by testing institutes in China, India and the Netherlands. *SNV*
37. Kimengsi JN (2015) Adopting the Use of Biogas as a Renewable Energy Source in Bui Division of Cameroon: Challenges and Blueprints *. *Renewable Energy Law and Policy: RELP*
38. Kinyua MN, Rowse LE, Ergas SJ (2016) Review of small-scale tubular anaerobic digesters treating livestock waste in the developing world. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2015.12.324
39. Lemma B, Ararso K, Evangelista PH (2020) Attitude towards biogas technology, use and prospects for greenhouse gas emission reduction in southern Ethiopia. *Journal of Cleaner Production*, *xxxx*, 124608. https://doi.org/10.1016/j.jclepro.2020.124608
40. Maes WH, Verbist B (2012) Increasing the sustainability of household cooking in developing countries: Policy implications. Renew Sustain Energy Rev 16(6):4204–4221. https://doi.org/10.1016/j.rser.2012.03.031
41. Makai L, Molinas M (2013) Biogas - An alternative household cooking technique for Zambia. *2013 IEEE Global Humanitarian Technology Conference (GHTC)*, 17–22. https://doi.org/10.1109/GHTC.2013.6713647
42. Mandelli S, Barbieri J, Mattarolo L, Colombo E (2014) Sustainable energy in Africa: A comprehensive data and policies review. Renew Sustain Energy Rev 37:656–686. https://doi.org/10.1016/j.rser.2014.05.069
43. Martinot E, Chaurey A, Lew D, Moreira JR, Wamukonya N (2002) Renewable energy markets in developing countries. Annu Rev Energy Environ 27:309–348. https://doi.org/10.1146/annurev.energy.27.122001.083444
44. Mas'ud AA, Vernyuy Wirba A, Muhammad-Sukki F, Mas'ud IA, Munir AB, Yunus Md, N (2015) An assessment of renewable energy readiness in Africa: Case study of Nigeria and Cameroon. Renew Sustain Energy Rev 51:775–784. https://doi.org/10.1016/j.rser.2015.06.045
45. Mengistu MG, Simane B, Eshete G, Workneh TS (2015a) A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. Renew Sustain Energy Rev 48:306–316. https://doi.org/10.1016/j.rser.2015.04.026
46. Mengistu MG, Simane B, Eshete G, Workneh TS (2015b) A review on biogas technology and its contributions to sustainable rural livelihood in Ethiopia. Renew Sustain Energy Rev 48:306–316. https://doi.org/10.1016/j.rser.2015.04.026

47. Milbrandt A, Uriarte C (2012) Bioenergy assessment tool.National Renewable Energy Laboratory15013 Denver West Parkway, Golden, CO 80401
48. Mohammed YS, Mokhtar AS, Bashir N, Saidur R (2013) An overview of agricultural biomass for decentralised rural energy in Ghana. Renew Sustain Energy Rev 20:15–25. https://doi.org/10.1016/j.rser.2012.11.047
49. Mohammed YS, Mustafa MW, Bashir N (2013) Status of renewable energy consumption and developmental challenges in Sub-Sahara Africa. Renew Sustain Energy Rev 27:453–463. https://doi.org/10.1016/j.rser.2013.06.044
50. Msibi SS, Kornelius G (2017) Potential for domestic biogas as household energy supply in South Africa. J Energy South Afr 28(2):1. https://doi.org/10.17159/2413-3051/2017/v28i2a1754
51. Muh E, Amara S, Tabet F (2018) Sustainable energy policies in Cameroon: A holistic overview. *Renewable and Sustainable Energy Reviews*, *82*(October 2017), 3420–3429. https://doi.org/10.1016/j.rser.2017.10.049
52. Mulinda C, Hu Q, Pan K (2013) Dissemination and Problems of African Biogas Technology. Energy and Power Engineering 05(08):506–512. https://doi.org/10.4236/epe.2013.58055
53. Mwakaje AG (2008) Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. Renew Sustain Energy Rev 12(8):2240–2252. https://doi.org/10.1016/j.rser.2007.04.013
54. Mwirigi J, Babulo B, Mugisha J, Walekhwa P, Melamu R, Nakami S, Makenzi P (2014) ScienceDirect Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass Bioenergy 70:17–25. https://doi.org/10.1016/j.biombioe.2014.02.018
55. Mwirigi J, Balana BB, Mugisha J, Walekhwa P, Melamu R, Nakami S, Makenzi P (2014a) Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass Bioenergy 70:17–25. https://doi.org/10.1016/j.biombioe.2014.02.018
56. Mwirigi J, Balana BB, Mugisha J, Walekhwa P, Melamu R, Nakami S, Makenzi P (2014b) Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. Biomass Bioenergy 70:17–25. https://doi.org/10.1016/j.biombioe.2014.02.018
57. Mwirigi JW, Makenzi PM, Ochola WO (2009) Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy Sustain Dev 13(2):106–115. https://doi.org/10.1016/j.esd.2009.05.002
58. Nevzorova T, Kutcherov V (2019) Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. Energy Strategy Reviews 26:100414. https://doi.org/10.1016/j.esr.2019.100414
59. Ohimain EI (2013) A review of the Nigerian biofuel policy and incentives (2007). *Renewable and Sustainable Energy Reviews*, *22*, 246–256. https://doi.org/10.1016/j.rser.2013.01.037
60. Okello C, Pindozzi S, Faugno S, Boccia L (2013) Development of bioenergy technologies in Uganda: A review of progress. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2012.10.004

61. Omer AM (2005) Biomass energy potential and future prospect in Sudan. Renew Sustainable EnergyReviews 9(1):1–27. https://doi.org/10.1016/j.rser.2003.12.011
62. Orskov ER, Anchang Y, Subedi K, Smith J (2014) Overview of holistic application of biogas for small scale farmers in Sub-Saharan Africa. Biomass Bioenergy 70:4–16. https://doi.org/10.1016/j.biombioe.2014.02.028
63. Osei-Marfo M, Awuah E, de Vries NK (2018) Biogas technology diffusion and shortfalls in the central and greater Accra regions of Ghana. Water Pract Technol 13(4):932–946. https://doi.org/10.2166/wpt.2018.100
64. Painuly J, Fenhann JV (2002) Implementation of Renewable Energy Technologies: Opportunities and Barriers: Summary of Country Studies. In *… Institute of Technology …*.
65. Parawira W (2009) Biogas technology in sub-Saharan Africa: status, prospects and constraints. Reviews in Environmental Science and Bio/Technology 8(2):187–200. https://doi.org/10.1007/s11157-009-9148-0
66. Pollmann O, Podruzsik S, Fehér O (2014) Social acceptance of renewable energy: Some examples from Europe and developing Africa. Soc Econ 36(2):217–231. https://doi.org/10.1556/SocEc.36.2014.2.5
67. Rasimphi T, Tinarwo D (2020) Relevance of biogas technology to Vhembe district of the Limpopo province in South Africa. Biotechnol Rep 25:e00412. https://doi.org/10.1016/j.btre.2019.e00412
68. Rastogi N (2016) *Pestle technique – Atool to identify external risks in construction projects*. 384–388
69. Roopnarain A, Adeleke R (2017a) Current status, hurdles and future prospects of biogas digestion technology in Africa. Renew Sustain Energy Rev 67:1162–1179. https://doi.org/10.1016/j.rser.2016.09.087
70. Roopnarain A, Adeleke R (2017b) Current status, hurdles and future prospects of biogas digestion technology in Africa. Renew Sustain Energy Rev 67:1162–1179. https://doi.org/10.1016/j.rser.2016.09.087
71. Ruane J, Sonnino A, Agostini A (2010) Bioenergy and the potential contribution of agricultural biotechnologies in developing countries. In *Biomass and Bioenergy*. https://doi.org/10.1016/j.biombioe.2010.04.011
72. Rupf GV, Bahri PA, De Boer K, McHenry MP (2015) Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2015.07.107
73. Rupf GV, Bahri PA, De Boer K, McHenry MP (2016) Broadening the potential of biogas in Sub-Saharan Africa: An assessment of feasible technologies and feedstocks. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2016.04.023
74. Sarakikya H (2015) Renewable Energy Policies and Practice in Tanzania: Their Contribution to Tanzania Economy and Poverty Alleviation. Int J Energy Power Eng 4(6):333. https://doi.org/10.11648/j.ijepe.20150406.12

75. Shane A, Gheewala SH, Fungtammasan B, Silalertruksa T, Bonnet S, Phiri S (2016) Bioenergy resource assessment for Zambia. Renew Sustain Energy Rev 53:93–104. https://doi.org/10.1016/j.rser.2015.08.045
76. Shane A, Gheewala SH, Phiri S (2017) Rural domestic biogas supply model for Zambia. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2017.05.008
77. Smith JU, Fischer A, Hallett PD, Homans HY, Smith P, Abdul-Salam Y, Emmerling HH, Phimister E (2015) Sustainable use of organic resources for bioenergy, food and water provision in rural Sub-Saharan Africa. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2015.04.071
78. SNV (The Netherlands Development Organization) (2018) Technical potential for household biodigesters in Africa. Available online on https://snv.org/assets/explore/download/technical_brief_-_technical_potential_for_household_biodigesters_in_africa.pdf. Accessed on 27 July 2020)
79. So D, Oo F, Eo Y (2020) Bioenergy technologies adoption in Africa: A review of past and current status. J Clean Prod 264:121683. https://doi.org/10.1016/j.jclepro.2020.121683
80. Surendra KC, Takara D, Hashimoto AG, Khanal SK (2014) Biogas as a sustainable energy source for developing countries: Opportunities and challenges. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2013.12.015
81. Surroop D, Bundhoo ZMA, Raghoo P (2019) Waste to energy through biogas to improve energy security and to transform Africa's energy landscape. In *Current Opinion in Green and Sustainable Chemistry*. https://doi.org/10.1016/j.cogsc.2019.02.010
82. Sustainable Energy for All (2013) *Etude diagnostique du secteur de l'Energie au Burundi dans le cadre de l'Initiative du Secrétaire Général des Nations Unies sur l'Energie durable pour tous (Sustainable Energy for All)*
83. Tangka J, Ketuama C, Ajaga N, Viyoi C (2016) Modelling of the Operation of a Small Generator Set Powered by Scrubbed Biogas from Cow Dung. Br J Appl Sci Technol 14(1):1–8. https://doi.org/10.9734/bjast/2016/22903
84. Terrapon-Pfaff J, Gröne MC, Dienst C, Ortiz W (2018) Productive use of energy – Pathway to development? Reviewing the outcomes and impacts of small-scale energy projects in the global south. *Renewable and Sustainable Energy Reviews*, *96*(October 2017), 198–209. https://doi.org/10.1016/j.rser.2018.07.016
85. UNDP Regional Bureau for Africa (RBA), U. R (2018) Transforming lives through renewable energy access in Africa UNDP ' s Contributions: UNDP Regional Bureau for Africa (RBA).UNDP Africa Policy Brief *Vol. 1, No. 1*, *1*(1)
86. United Nations (2015) The Millennium Development Goals Report. *United Nations*, 72. https://doi.org/978-92-1-101320-7
87. United Nations Economic Commission for Africa (UNECA) (2018) Achieving SDG 7 in Africa. United Nations, Department of Economic an Social Affairs

88. Venkata Ramana P, Michael T, Sumi M, Kammila S (2015) The State of the Global Clean and Improved Cooking Sector. *ESMAP and GACC*. https://doi.org/007/15
89. Verbist B (2018) *Development of a viable domestic biogas sector: Challenges and successes in Africa*
90. Walekhwa PN, Mugisha J, Drake L (2009) Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. Energy Policy 37(7):2754–2762. https://doi.org/10.1016/j.enpol.2009.03.018
91. Walwyn DR, Brent AC (2015) Renewable energy gathers steam in South Africa. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2014.08.049
92. Wassie YT, Adaramola MS (2019) Potential environmental impacts of small-scale renewable energy technologies in East Africa: A systematic review of the evidence. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2019.05.037
93. WEC (World Energy Council) (2004) 2004 Survey of World Energy Resources. Available online at https://www.worldenergy.org/assets/downloads/PUB_Survey-of-Energy-Resources_2004_WEC.pdf. Accessed on 12 April 2020
94. Wilson L (2007) Promoting biogas systems inkenya, A Feasibility Study Biogas for Better Life An African Initiative. *Analysis*
95. Zahari AR, Romli FI (2019) Analysis of suborbital flight operation using PESTLE. *Journal of Atmospheric and Solar-Terrestrial Physics*, *192*(August 2018), 104901. https://doi.org/10.1016/j.jastp.2018.08.006

# Figures

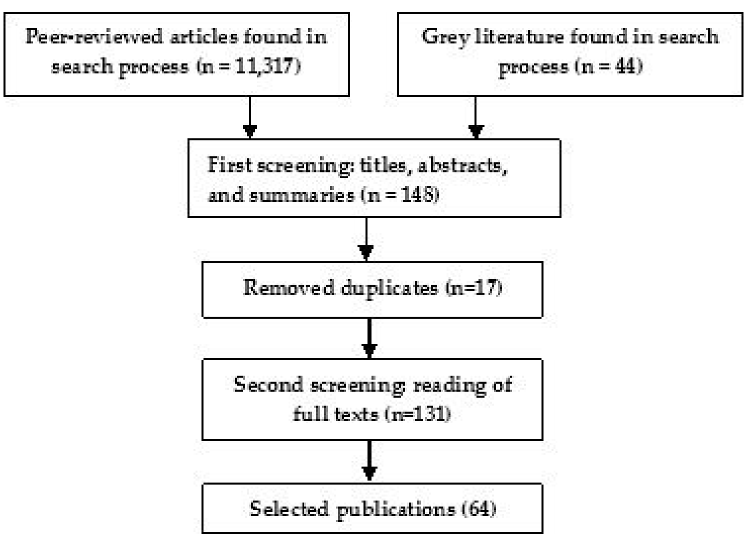
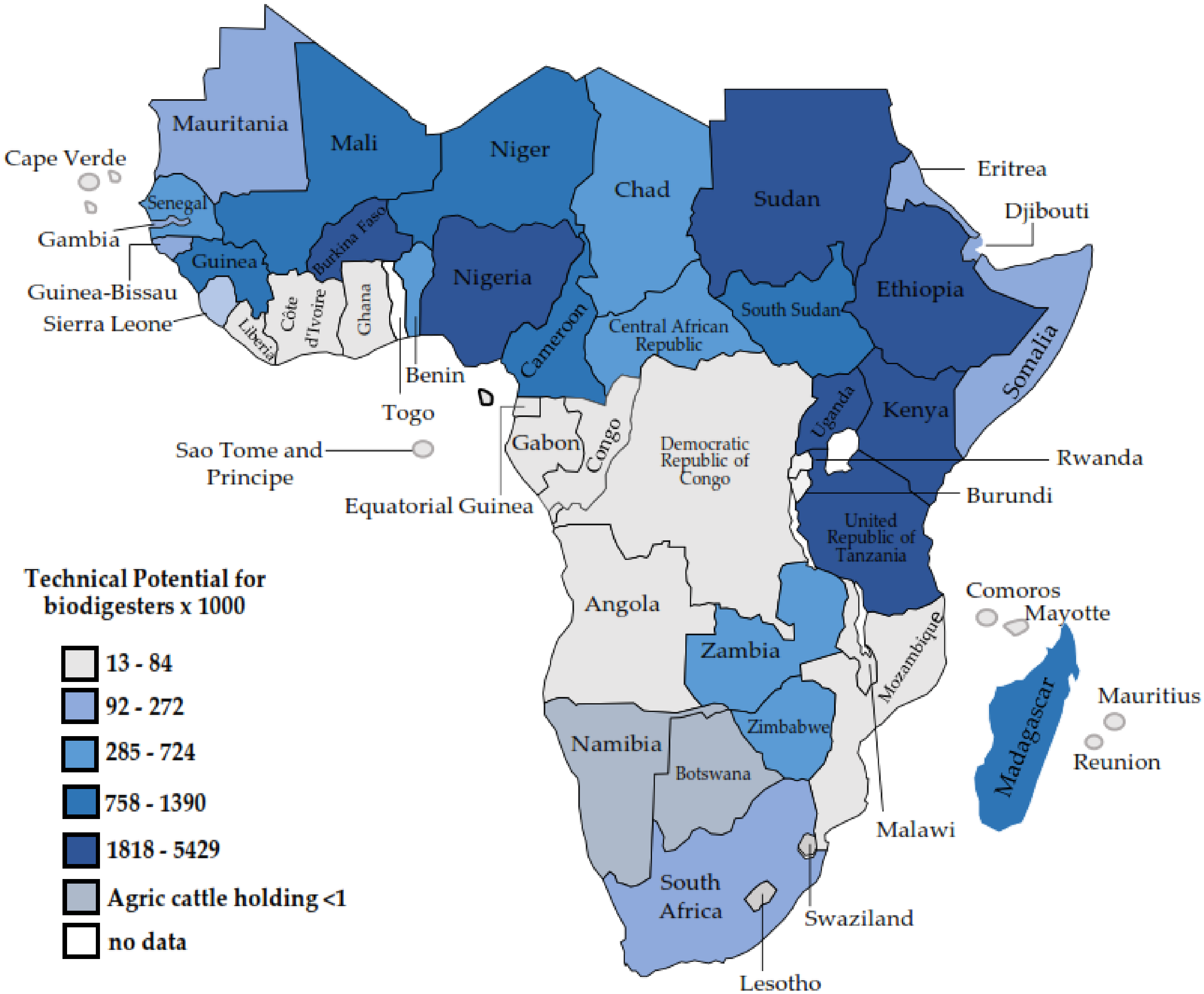



**Figure 1**

Stages of the selection of publications for the study

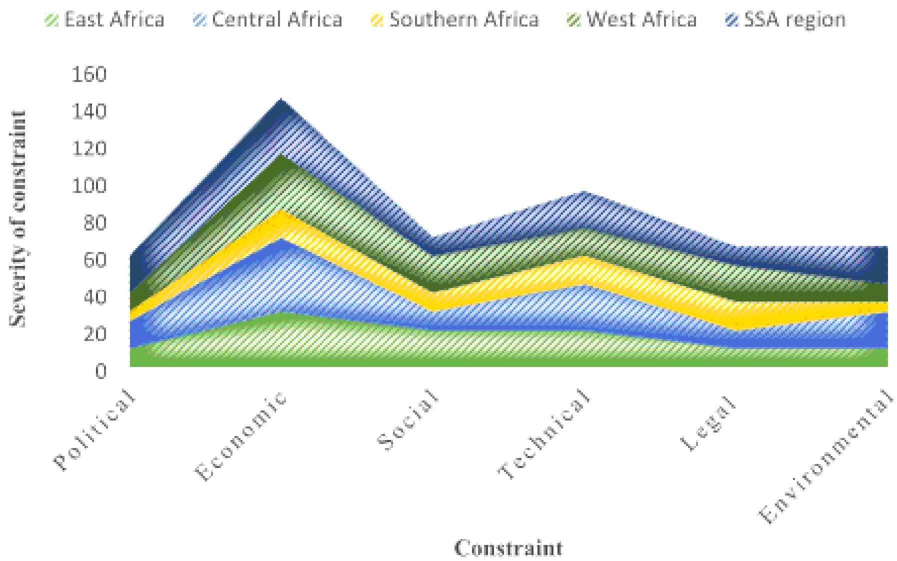
## Figure 2

Chosen PESTLE factors affecting small-scale biogas technology




## Figure 3

Quintile division of the technical potential of household biogas plants by country in SSA Source: Data from SNV (2018).




### Figure 4

Extent of PESTLE aspects in SSA

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