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REVIEW ARTICLE

Impact of market 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 are required 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 development of the technology in the SSA region. The production of biogas with small-scale plants is commonly done 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 policy improvements, broader 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 greater progress in reducing the constraints. To achieve the sustainable development of the technology, there is a need to further address the PESTLE constraints at national and regional levels. This study partly deduces that the unsustainable production, use, and inadequate regulation of the small-scale biogas sector are delaying its transition in the SSA region.

Keywords Energy access · Anaerobic digestion · Bioenergy policy · Developing countries · Sustainable development · PESTLE constraints

Abbreviations

ABPP	Africa Biogas Partnership Programme
BGPs	Biogas plants
BGT	Biogas technology
CDM	Clean development mechanism
CSO	Civil Society Organisation
GHG	Greenhouse gas
ha	Hectare
HH	Household
IFAD	International Fund for Agricultural Development
IRENA	International Renewable Energy Agency
PESTLE	Political, economic, social, technological, legal, and environmental
REFIT	Renewable energy feed-in tariff
RET	Renewable energy technology
SDG	Sustainable development goal
SE4ALL	Sustainable energy for all
SNV	The Netherlands Development Organization
SSA	Sub-Saharan Africa
UNDP	United Nations Development Programme

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Introduction

Biogas technology is considered a cost-effective method that can be used to reduce greenhouse gas (GHG) emissions from biomass or organic wastes, reduce deforestation, household air pollution, and improve rural sanitation through appropriate waste management. Biogas is clean 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 PESTLE factors affecting the development of small-scale biogas technology (BGT) in SSA. Since the introduction of biogas technology in Africa after World War II, small-scale biogas development still needs to be researched (Parawira 2009). Karekezi and Kihyoma (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; 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 the 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). In 2013, the United Nations initiated the sustainable energy for all (SE4ALL) 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 improved energy efficiency (UNDP 2018). Three main approaches have been commonly used to deploy biogas technology in developing countries. These include the holistic, life cycle, and the market-oriented approaches. The holistic approach focuses on the acceptability and performance of the biogas plant. The emphasis of this approach is on the adjustment of the existing processes for the management of solid waste, improvement in the utilisation 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 Netherlands Development Organization (SNV), International Humanist Institute for Cooperation with Developing Countries (Hivos), German Technical Cooperation (GIZ), and Heifer International. Therefore, a market analysis of the outcomes of these biogas technology interventions is necessary to learn past lessons and provide perspectives for future development.

Evidence from SSA shows that biogas plants have contributed to improving the livelihoods of rural households through demonstrated positive impacts on the social, financial, human, and physical capital (Balgah et al. 2018). The increasing wood resource scarcity makes the market price of firewood and charcoal more expensive, which keeps households in poverty (IRENA 2018a). Conversely, biogas technology lowers energy and fuel costs, reducing poverty (Rahman et al. 2021). In a comparison of firewood and biogas, Buysman (2015) showed that biogas technology reduced particulate matter concentration and carbon monoxide (CO), resulting in improved indoor air quality. The residues of anaerobic digestion (digestate) have been used as organic fertiliser and biopesticide to improve food production (Valentinuzzi et al. 2020). The use of biogas technology to treat domestic wastewater, organic waste, brown water, blackwater, and excreta has improved sanitation in households (Mang and Li 2010). Biogas technology can reduce the exploitation of trees for firewood (Parawira 2009) and contribute to carbon sequestration in soils, soil erosion, degradation, and reduced deforestation (Al 2011).

In December 2022, SSA made up 14.65% of the world's population. Evidently, SSA has the lowest energy access rates in the world. In 2019, access to electricity in SSA 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. In SSA, biogas technology consists of usually small-scale biogas digesters, mostly less than or equal to 10 m^3 in volume and marred with several development constraints. Between 1980 and 2000, only about 2400 small-scale biogas plants were installed in Sub-Saharan Africa through donor and demonstration projects (Martinot et al. 2002). In 2012, the total number of small-scale biogas plants constructed in the SSA region rose to nearly 23,000 and to about 75,561 in 2018 (Freeman and Seppala 2019). From the market development point of view, this study aims at collecting the PESTLE constraints and analysing them to reveal their implications for the future development of the technology. 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 approach 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 and Romli 2019). It is used to identify the risks belonging to stated factors such as political, economic, social, technological, legal, and environmental (Rastogi 2016). Rahmatzafran et al. (2020) applied the PESTLE approach to study the biogas markets and frameworks in Argentina, Ethiopia, Ghana, Indonesia, and South Africa. Based on the insights from this study, a SSA regional study was necessary to reveal the PESTLE aspects of the small-scale biogas market and their implications for the future development of the technology. The PESTLE approach is relevant to understanding the interaction of small-scale BGT and the SSA operation environment (macro-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 and laws enacted by local communities, governments, and regions 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 and 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).

Methodology

This study geographically covered the Sub-Saharan African region. According to the United Nations, the region comprises forty-nine (49) countries located south of the Sahara Desert. A two-stage conceptual approach was applied to assess the impact of PESTLE constraints on the development of small-scale biogas technology in this region. Firstly, a systematic review was performed to identify and categorise the PESTLE constraints. Secondly, an impact assessment of the constraints was 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.

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 biogas plants (BGPs) in the region? What are the impacts of the constraints on the sustainable development of small-scale BGPs? 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. To identify country-specific grey literature search, keywords such as biogas AND ‘name of the country’ were used.

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 was used to obtain more information to substantiate the direct information previously collected. Figure 1 shows the stage stages of the selection of articles.

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

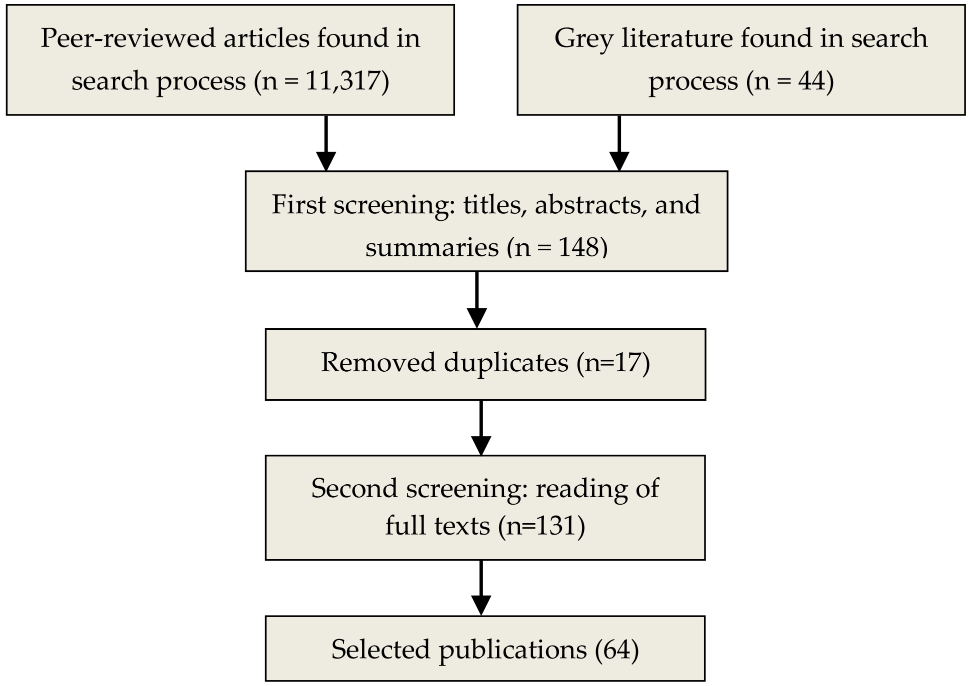


Fig. 1 Stages of the selection of publications for the study

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 small-scale BGPs have been disseminated as a means of alleviating poverty and hunger in SSA. Hence the focus is on the small-scale digesters.

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 about a given PESTLE aspect was discussed, and a common best-fit description or analysis was adopted.

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 (Fig. 3).

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 East, West, Southern, and Central Africa. Weighting factors were used to represent the severity of the PESTLE constraints in each sub-region. The weight of each constraint was gotten by dividing the number of publications reported on the constraint by the total number of publications (64) multiplied by 10. The higher the weighting factor, the higher the severity of the constraint and vice versa. The results were plotted against each constraint and presented in Fig. 4.

Results and discussion

Search results

From the literature search, a total of 11,361 publications were obtained. A total of 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

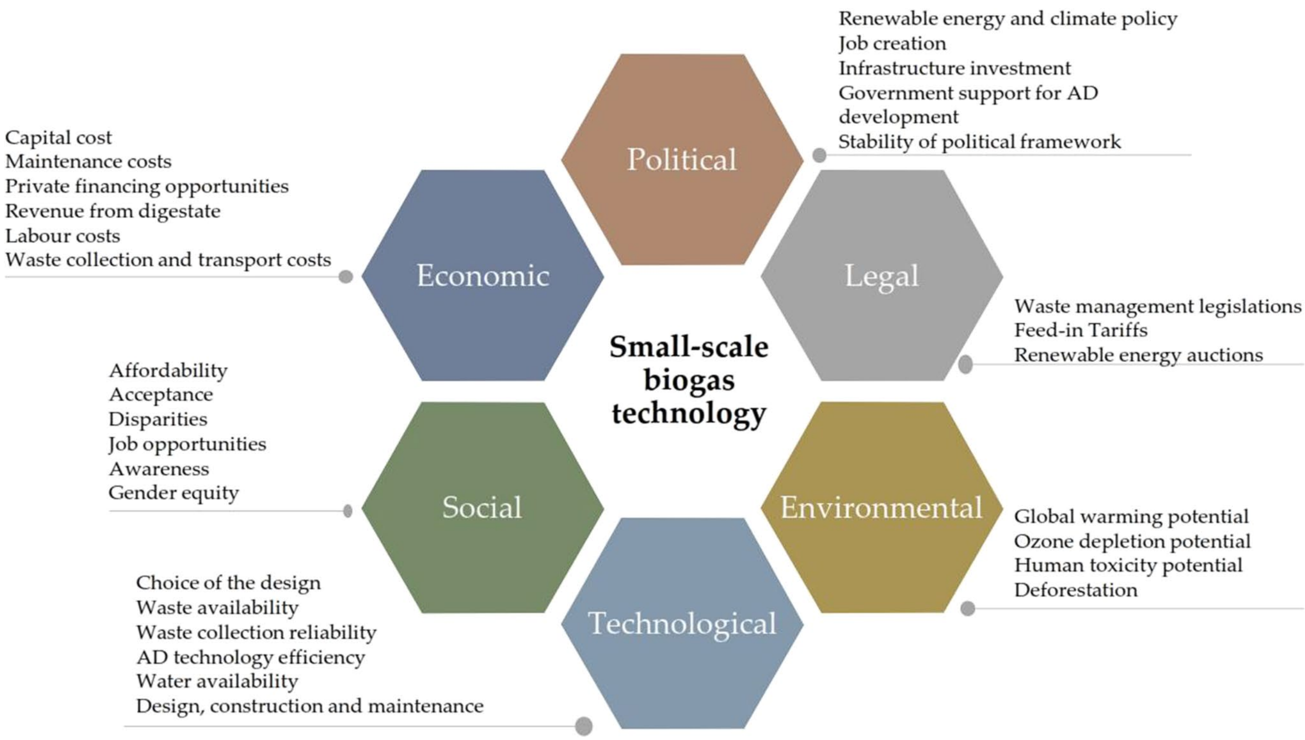
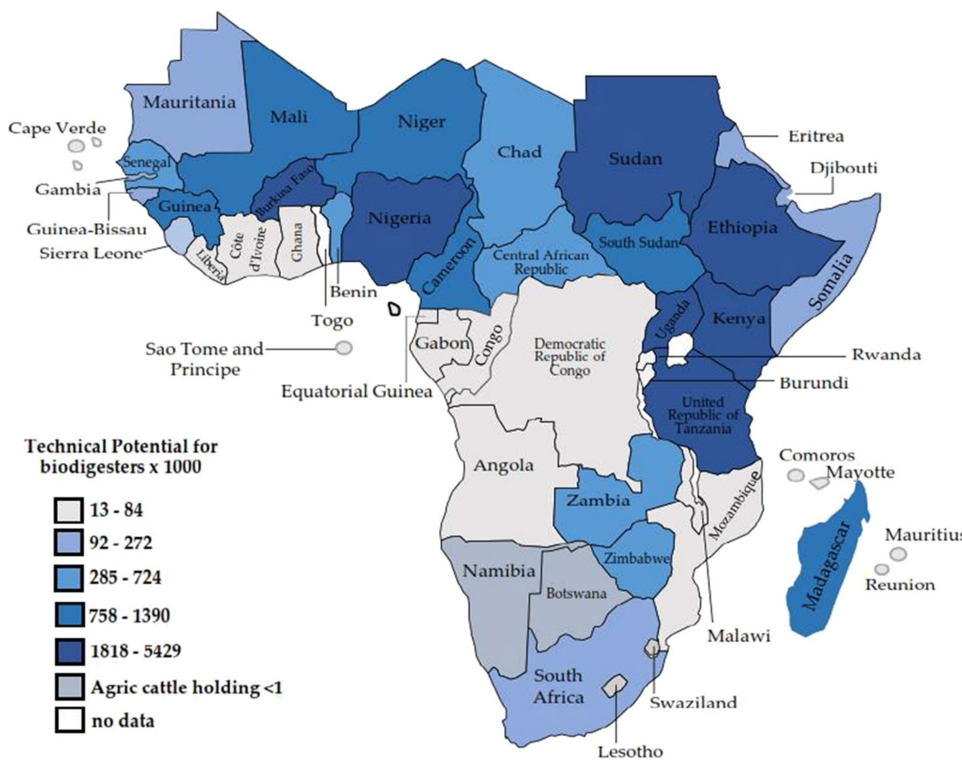


Fig. 2 Selected PESTLE factors affecting small-scale biogas technology

Fig. 3 Quintile division of the technical potential of household biogas plants by country in SSA. Source: Data from SNV (2018)



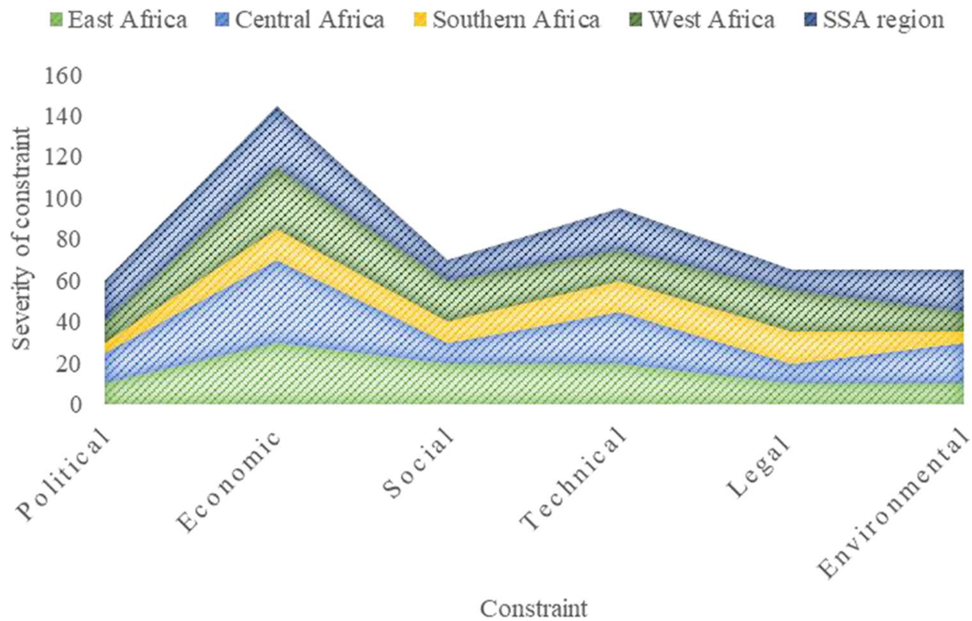


Fig. 4 Severity of PESTLE constraints in SSA

Table 1 Summary of the articles collected from the literature search

Geographical zone/country	Reference (s)	Σ
Africa, SSA	Dahunsi et al. (2020), Surroop et al. (2019), Griffith-Jones et al. (2012), Roopnarain and Adeleke (2017a), Mandelli et al. (2014), Bamikole Amigun et al. (2011), Verbist (2018), Mulinda et al. (2013), Roopnarain and Adeleke (2017b) Kinyua et al. (2016), Cheng et al. (2014), Surendra et al. (2014), Maes and 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. (2014), Mohammed et al. (2013), Parawira (2009), Gebreegziabher et al. (2014), Nevzorova and Kutcherov (2019), Terrapon-Pfaff et al. (2018), Amigun and Blottnitz (2009)	26
East Africa	Walekhwa et al. (2009), Wassie and Adaramola (2019) Karanja and Gasparatos (2019), Mwirigi et al. (2009), Kamp and Forn (2016), Mengistu et al. (2015), Kamp and Forn (2015), Sarakikya (2015), Mwakaje (2008), Omer (2005), Wilson (2007)	12
Central Africa	Muh et al. (2018), Tangka et al. (2016), Fondufe and Kimengsi (2015), Balgah et al. (2018)	4
Southern Africa	Walwyn and Brent (2015), Boyd (2012), Msibi and Kornelius (2017), Rasimphi and 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 and 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

these 64 publications, 58 were peer-reviewed and 6 were grey. The distribution of the publications studied is shown in Table 1.

Countries of the region where national biogas programmes were implemented produced documents with useful information 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, and Senegal. A variety of grey literature on these countries was found.

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:

Political

Political constraints to the development of small-scale BGT are still evident. SSA is still faced with several bottlenecks regarding the consideration of small-scale BGT issues related to the planning 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 for 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 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 the national governments of the region to develop and implement biogas programmes. The African bioenergy policy framework and guidelines have existed since 2013 (AUC-ECA 2013). In spite of this existence, countries are in the process of preparing or are still beginning the preparation of this policy. The passivity of some governments remains a threat to promoting biogas technology (Pollmann et al. 2014). 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. 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). The number of these jobs created has not been realistically tracked. Socio-political instability in some SSA countries has led to a low rate of adoption and dissemination of these 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 the technology. Under a stable socio-political situation, the biogas potential is an asset.

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**.** The cost of the technology is mainly dependent on the plant's geographical location (Amigun and Von Blottnitz 2010). Boyd (2012) reported on South Africa's inadequate access to finance. Generally, financial institutions in the region still lack financing structures for small biogas projects (Parawira 2009). The revenue from the digestate otherwise referred to as organic fertiliser is widely not yet estimated for most SSA countries. In South Africa, Mdlambuzi and Tsubo (2021) showed that co-application of digestate and mineral fertiliser in crop production reduced farming costs. There is an information deficit on the economic viability of available biomass and waste resources (Dahunsi et al. 2020). Due to the clustering of poor or average homes in some countries, construction space is seen as a constraint to the adoption of 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 one of the factors affecting the adoption of small-scale biogas technology is the small size of landholdings. 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 and 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 proved to be too expensive for the average Ugandan to afford. They added that a cheaper flexible balloon digester was affordable, but there is no evidence of the design's economic viability. Generally,

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	1209.00	Osei-Marfo et al. (2018)
Ghana	6	2004	1358.00	Osei-Marfo et al. (2018)
Ghana	6	2011	2189.00	Osei-Marfo et al. (2018)
Ghana	6	2015	851.00	Osei-Marfo et al. (2018)
Ghana	10	2011	3169.00	Osei-Marfo et al. (2018)
Kenya	8	2004	2973.00	Osei-Marfo et al. (2018)
Uganda	6	2004	1005.00	Osei-Marfo et al. (2018)
Rwanda	6	2007	859.00	Amigun and Blottnitz (2010)
South Africa	6	2007	1149.86	Amigun and Blottnitz (2010)

small-scale biogas users still find it challenging to afford the complete small-scale BGPs. Parawira (2009) recommended the need to provide loans and subsidies to encourage and promote biogas technology. Market incentives for biogas technology include '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 could collect government subsidies if they adopted technologies that have socially desirable characteristics (Mengistu et al. 2015).

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. 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 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 heaters (Mwirigi et al. 2014), biogas lamps (Khandelwal and Gupta 2009; Mwirigi et al. 2014), and biogas electricity generators (Tangka et al. 2016; Mwirigi et al. 2014).

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 a need to improve the skills base of the community to help maintain the technology. The dissemination needed to be done through capacity building, governance and integrated development (Ghimire 2013). 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 women in the decision for procurement of the BGPs. The decision to install the BGPs was made mainly 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 of the role of small-scale BGT. In the region, 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 and 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 nonusers tend to have a positive attitude towards biogas technology. About 52.5% of the nonusers did not have adequate information, while the installation costs deterred 25% of the nonusers.

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 and Sonder (2007). Two leading indicators used were 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. The latest study by SNV (2018) showed that the technical potential for household biogas plants in Africa is 32.9 million installations. By 2012, the total number of constructed BGPs had risen to nearly 23,000. By December 2018, this number rose to 75,561 with the involvement of other agencies under the umbrella of the Africa Biogas Partnership Programme (ABPP) (Freeman and Seppala 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 household biogas plants in SSA.

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 (Janssen and Rutz 2012). Prefabricated biogas digesters following the above philosophies are also present in the region (Cheng et al. 2014). Biogas plants' size is based upon: (i) the (daily) amount of available feeding material; (ii) the biogas requirement of the family (Freeman and Seppala 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. An overview of the main types of small-scale biogas plants in SSA is visible in Table 3.

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 in other parts of the world, the switch from the floating drum design to the fixed dome design is increasing (Janssen and Rutz 2012). 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). 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 (Janssen and Rutz 2012).

Anaerobic digestion efficiency Biogas production through anaerobic digestion of organic waste using small-scale BGPs is a continuous learning process in the region. Parawira (2009) in Uganda identified that household biogas digesters in SSA usually lack facilities to remove sand, stones, and other nondigestible materials, which accumulate over years of use, thereby decreasing the volume and efficiency of the

Table 3 Types of digesters

Type of digester	Advantages	Disadvantages	Source
Fixed dome digester	• Eliminates the use of costly mild steel gasholder • Relatively low installation cost (about two-thirds of the cost of the floating drum digester) • Does not have moving parts • Does not have rusting steel parts • Long lifespan (20 years or more) • Possible underground construction • Saves space • 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 • Gas pressure fluctuates substantially	(Mulinda et al. 2013). (Janssen and Rutz 2012)
Floating drum	• Has a simple operation design • 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) • 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) • Requires regular maintenance costs due to painting	(Mulinda et al. 2013), (Janssen and Rutz 2012)
Polyethylene digesters (including high density polyethylene digesters)	• Technically cheapest and simple design to install • Easy transportation • Shallow construction • High digester temperatures • Easy cleaning, emptying, and maintenance	• Short lifespan (about 5 years), • High risk of damage, • No real local employment creation, little scope for self-help • Low gas storage is a limitation	(Kabyanga et al. 2018), (Janssen and Rutz 2012)

digesters**.** SSA has favourable conditions for biogas technology, namely a suitable tropical climate in most parts of the region (Rupf et al. 2015). From 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 and Seppala 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 and Kihyoma (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 research and development (R&D) is also needed to explore better substrates to boost the efficiency and performance of biogas plants. Land management and the method of rearing are 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, Austin (2003) 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 in 2020 reported that only 27% of the population of SSA have access to safely managed drinking water. With low access to water, the use of small-scale biogas plant will continue to be impeded in the region.

Design, construction, and maintenance In SSA, inexperienced technicians and consultants have resulted in poor-quality BGPs. This is a result of the 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 (Dahunsi et al. 2020) and flawed or wrong operation and maintenance culture (Dahunsi 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 nonoperational due to incomplete installation, other technical problems, and limited supervision. Waste collection reliability is still not measured. Where the biogas systems are properly designed, they have contributed to the reduction of fuelwood collection time by women and children in the region.

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, which excludes small biogas projects in rural communities. 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 of obtaining duty-free status is unclear to local entrepreneurs in the region. No tax exemptions exist in Tanzania and Uganda (Clemens et al. 2018), as well as in most other countries in the region. According to IRENA (2018b), renewable energy auctions can be successfully implemented in South Africa, Uganda, and Zambia. Only large-scale biogas technology producing marketable electricity can benefit from these auctions. Small-scale biogas technology still lacks cost legal frameworks for development incentives in the region.

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 accelerated deforestation and led to soil erosion, desertification, and an increased risk of flooding and biodiversity loss (Parawira 2009). In Africa, biogas production reduced deforestation due to fuelwood demand by between 6 and 36% in 2010 and potential between 4 and 26% by 2030 (Matthews et al. 2014). The clean development mechanism (CDM) is inadequately applied to 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 a 24% disability-adjusted life year (DALY). There is a need to quantify the environmental benefits of biogas in SSA. For example, in Ethiopia, each household biogas plant has the potential to reduce about 6024 kg of CO_2e per year of GHG emissions (Lemma et al. 2020). Also, around 13 kg CO_2e/tonne can be saved when digestate replaces mineral fertiliser (Litmanen and Kirchmeyr 2014). This data is absent for most countries in the region. 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 (United Nations 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.

Impact of PESTLE constraints

The analysis in the "Data analysis" section shows that the constraints, in decreasing order of severity, are economical, technical, political, social, environmental, and legal. Considering the most significant constraint (economical constraint), the Southern Africa sub-region has lowered the economic constraints more than any other sub-region in SSA. The affordability of the small-scale BGPs is the least in East Africa and highest in Southern Africa. Most of the population in need 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 sources to finance this technology for resource-poor households. The implementation of climate change agreements (including the clean development mechanism) on the reduction of GHG emissions remains a potential source of funding for the local biogas projects. A useful action would be the development of context-based business models and more job creation that recognise 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 have prevailed and 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 instruments needs to be the focus of the process 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. 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 sub-regions in reducing policy constraints. This justifies the low uptake and dissemination in the sub-region. Regarding social impacts, inadequate knowledge, human capacity, and gender mainstreaming in biogas projects across the region have 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). In 2022 (about 12 years later), the region is still to make strides regarding this issue. Due to slow policy changes, access to and control of land has limited women's control over 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 in reducing these defects. Legal issues, including standards and regulations that were addressed reduced the institutional burden on the adopters. These are more and more needed to increase users' willingness and engagement in developing the technology. Due to the inability of the technology to meet household energy needs, especially for cooking, deforestation and indoor pollution (with devastating health consequences) have persisted.

Policy implications

This study deduces that the core action to reduce the PESTLE constraints is to improve the financing of the technology. Some elements to consider are providing subsidies, mobilising international climate funds, tax exemptions, and promoting local entrepreneurship involving more women. Local finance institutions should be motivated to develop financing schemes for small-scale biogas projects. Extension services should be designed to enable users to sustain the technology. This can be achieved through the socio-technological changes in rural biogas energy systems. This will complement the smooth transition to the technology as targeted by the SDG7 by 2030 and the Agenda 2063 of the African Union. Most of the reported biogas plants in the region are programme-based (constructed through demonstrations and foreign-funded projects in partnership with the governments). There is still inadequate reporting on the actual built capacity (some household-funded biogas plants have not been reported). This highlights the need to consider improving data management at local, national, and regional levels. Developing the human capacity to develop technology is necessary. Finally, there is a need to promote local research and transfer of good practices from similar projects in other parts of the world, including Nepal, Vietnam, China, and India.

Conclusion

Despite the introduction of biogas technology in SSA in the mid-twentieth century, its market share compared to other renewable energy sources is still lower. Reforms are still needed to boost its adoption and dissemination. The development of small-scale biogas technology in SSA is still influenced by political, economic, social, technological, legal, and environmental constraints. In addition, institutional and geospatial factors influence this technology. The development of small-scale biogas technology in SSA still requires appropriate financing schemes and technological innovation to increase efficiency, reliability, and performance. Over the past two decades, civil society organisations (CSOs), including SNV, Hivos, and Heifer International, have been the leading 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. The PESTLE inadequacies still require many governmental and CSO responses to boost the adoption and dissemination of the technology in the region.

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