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EXPLORING ENABLERS AND BARRIERS FOR UPSCALING BIOENERGY TECHNOLOGIES FOR SUSTAINABLE BIOGAS ADOPTION IN NIGERIA THROUGH A STAKEHOLDER PARTICIPATORY APPROACH

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ABSTRACT

This study aims to explore enablers and barriers to upscaling biogas technology as an alternative energy source in Nigeria's rural households through a stakeholders' participatory approach. Using a mixed methodology, stakeholders were identified through a critical review of national energy policies and interviews; they were chosen from state and national ministries, rural women leaders,

Introduction

Background

Biomass as a fuel has experienced a significant transformation from burning organic material such as wood fuel, residues, and organic wastes for heating to a smarter application in biogas for heating and electricity generation

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farmers' associations, energy investors, financial institutions, and energy regulators. Following this, a stakeholder workshop was conducted involving approximately 50 participants, utilizing a participatory approach. A SWOT analysis was then applied to evaluate stakeholders' input and opinions from the workshop. Results revealed that Nigeria has abundant feedstock, and addressing indiscriminate waste disposal would promote biogas technology as a clean energy alternative. Appropriate trade-offs and synergies among the identified barriers and enablers were presented as reliable measures to enhance further the sustainable adoption of this clean energy solution, complemented by strategic action plans.

Keywords: biogas adoption, clean cooking, Nigeria, feedstock, SWOT, participatory stakeholder

(Kalak, 2023). The global consumption of firewood and charcoal has remained relatively constant, but the use of wood chips and wood pellets for electricity (biopower) generation and residential heating doubled in the past decade and will increase steadily (Guo et al., 2015). The transformation of biomass fuel has gained acceptance in many developed economies to generate electricity, at about 20% to 40% efficiency, while many emerging economies still use biomass in its raw state for outdoor and indoor cooking, with about 18% efficiency, causing emissions that pollute the immediate environment (Ballard-Tremeer & Jawurek, 1996; IEA, 2007). Also, in many emerging economies, like in sub-Saharan African countries and Asia, biomass fuel has been used inefficiently by burning biomass for cooking and heating, with little industrial application (Prasad, 2011).

Bioenergy refers to the energy uses of biomass, whether for heating, power generation or transport. Burning pure biomass for heating and cooking purposes among rural Nigerian households has gained significance; however, this approach of generating bioenergy has a detrimental impact on the vulnerable population of the communities (Ugwu et al., 2022). Burning biomass to generate bioenergy could be made more efficient, which means extracting more energy from the same material input, and avoiding negative environmental effects potentially caused by bioenergy production (EEA, 2013). The efficient conversion of biomass would maximize the available local feedstock and enable meeting the energy demand, especially for heating, cooking and lighting purposes for more people.

An efficient waste-to-fuel conversion technology, as a reliable approach that is environmentally friendly and supports a circular bioenergy economy, is the second-generation biofuel (Kowalski et al., 2022). An application of the second-generation

biofuel is the Anaerobic digester (AD) process (Muthudineshkumar & Anand, 2019) which is a chemical process that takes in biomass feedstocks (such as animal waste) in a reactor in the absence of oxygen to generate biogas and digestate which is a good source of organic fertilizers (Abdullahi et al., 2015; Adeleke et al., 2023). The biogas resulting from AD is mainly methane and carbon dioxide (the same that is generated from landfills with the tendency to cause global warming), with traces of water vapour (Itodo et al., 2021). It implies that using organic waste and agricultural or forestry residues as feedstock is more resource efficient than many plant-based feedstocks, as it does not compete for land and water resources and serves as a potential sink for greenhouse gases that would have been emitted into the atmosphere. Despite the enormous benefits of waste-to-fuel conversion, many developing nations are still heavily dependent on inefficient wood-based biomass to meet their daily energy needs.

For instance, nearly half of the world's population and about 81% of households in Sub-Saharan Africa rely on wood-based fuel as their dominant source of energy (International Energy Agency, 2023). In 2021, over 83 % of Nigerians lacked access to clean cooking technologies and fuels, as about 175 million Nigerians depend on solid fuel as a source of fuel for cooking (World Health Organization, 2024). Heavy reliance on dirty cook fuel caused about 128 million deaths globally in 2019 (Murray et al., 2020). Of these, 84,000 were children under 5. Nationally, over one in ten deaths of children under the age of 5 is caused by household air pollution. In addition, the high demand for wood fuel has largely contributed to an estimated 100 million cubic meters of firewood being consumed annually, making Nigeria one of the highest growth rates of deforestation in the world, at over 3.3% per year (Yusuf & Razaq, 2023). As a result, the country lost over 1.33 Mha (9.3%) of tree cover, translating to around 724 $MtCO_2e$ emissions between 2001 and 2023 (Watch, 2024).

Cooking energy is also a source of short-lived climate pollutants such as black carbon (BC), which impacts both air pollution and global warming. Biomass burning in traditional cookstoves represents 57 % of the national BC emissions. In 2015, a significant share of Nigeria's greenhouse gas emissions arose from burning solid fuel during household cooking, which was estimated to be 31 MtCO2e (NDC, 2021). The Nigerian population is expected to double in 2050, reaching about 375 million and making it the world's most populous country (UNDESA, 2022). If immediate efforts are not taken to curb emissions from cooking through the burning of inefficient raw biomass, the undesirable impact of pollution on human health could worsen, causing more child mortality and making worse the health impact of already vulnerable people, and leading to further loss of the country's natural ecosystem through deforestation. Universal access to clean cooking is crucial for achieving national development and climate goals through investment in renewable energy, its adoption and penetration.

However, efforts are underway to develop a comprehensive clean cooking policy in Nigeria, based on existing evidence and best practices. However, there is a need to explore the dynamics of biogas technology, its barriers and enablers, in Nigeria's clean cooking policy. It is against this backdrop that this study aims to explore sustainable biogas adoption strategies for national development. Specifically, the study will investigate how stakeholders' opinions inform strategic biogas adoption and penetration towards National biogas policy. In addition, the study will investigate the adoption and penetration of biogas through the lens of relevant stakeholders and the obstacles and opportunities of the biogas technology towards Nigeria's clean energy policy development. On this note, there is a need to explore the dynamics of biogas technology its barriers and enablers in Nigeria's clean cooking policy. Hence, the study aims to use a stakeholder participatory approach to explore sustainable biogas adoption and penetration and strategies to upscale biogas technology in Nigeria.

Study Area

Nigeria is located on the west coast of Africa and is bordered by the Gulf of Guinea to the south, Cameroon to the East, Niger to the North and the Benin Republic to the west. It has a land area of 923,768 km^2. It lies within the longitudes 2.72^0E and 14.64^0E and latitudes 4.32^0N and 14^0N. The country has an ambient temperature of 27^0C and is located in the tropics. Nigeria's population grows at about 3.5% per annum, with its population being the largest in Africa at over 200 million (NBS, 2023; 2022). The country struggles to meet its overall energy demand. Her inability to meet its energy demand has endangered about 75% of Nigeria's population, as many of them still rely on solid fuel (biomass) for their household cooking and heating needs and this poses a threat to the health and safety of end-users, mainly women and children (FMEEM, 2022).

The location of Nigeria has provided an endowed appreciable biomass resource such as agricultural residues, livestock wastes, human and municipal solid wastes, aquatic biomass, energy crops and forest residues. However, several of the resources, particularly agricultural residues, have competing uses, such as livestock feed and soil rejuvenation. Nigeria's biomass energy is largely contributed to by agro-residues, municipal wastes and livestock wastes, while forest residues contribute the least (Ojolo et al., 2012). Agricultural residues have an energy potential of about 1.09 EJ, with cassava, maize, oil palm, plantain, rice, and sorghum being the major contributors. Animal wastes, municipal solid waste, and forest residues have energy potentials of 0.65, 0.11, and 0.05 EJ, respectively, while the potentials of wood fuel and charcoal are 0.38 and 0.05 EJ, respectively (Ojolo et al., 2012). An estimation of the technical energy potential of the biomass resources revealed that about 2.33 EJ could be generated from the available resources in Nigeria, and the potential is expected to grow from about 5.5

EJ in 2020 to about 29.8 EJ in 2050 (Ojolo et al., 2012). In addition, Nigeria's pastoral farming potential has about 22,378,374 Cattle; 53,061,143 Sheep; 99,879,799 Goats; 9,299,563 Pigs and over 425,790,456 Poultry, where their residues and waste are good sources of biogas (FMAFS, 2023).

In a comparison with crude oil and fuelwood potential, Adeoti et al. (2001) compared the value of biogas from plant residues and animal excretion with some conventional fuel sources. The study revealed that in 1999, Nigeria's biogas potential represented a total of $3.78 \times 10^6 m^3$ of biogas/day, or $1.38 \times 10^9 m^3$ of biogas/year, or an annual equivalent of 4.81 million barrels of crude oil, or 6.9×10^6 tons of fuelwood. The study further projected the annual increment (minimum value) of biogas as $138.7 \times 10^6 m^3$ or an annual equivalent of 0.48 million barrels of crude oil, or 0.69×10^6 tons of fuelwood. The livestock resources for 2023 presented in Figure 1 reveal that from the available data in the livestock sector, cows, goat and poultry are evenly distributed in the thirty-six states in the country. The Northern part has a high distribution of livestock within its states.

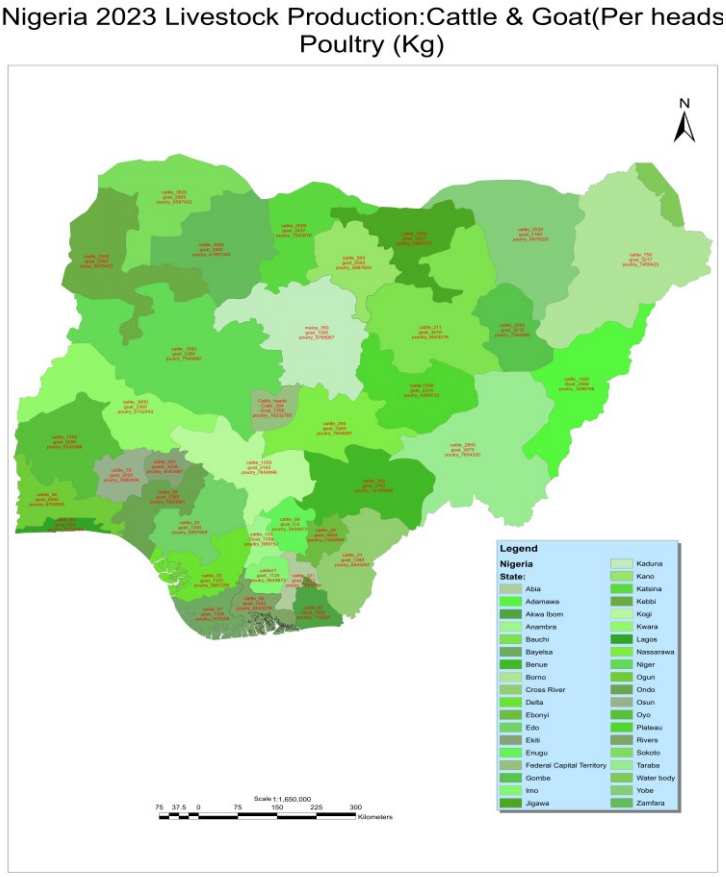

Figure 1. Estimated livestock distribution in Nigeria according to state (Data source: FMAFS, 2023).

2.0 Methodology

This section reviews the literature, highlighting stakeholders' participation in policy. The method will provide the approaches to answer the study's research question and objectives. These were done through a stakeholders' participatory (SP) approach and insights obtained were subjected to Strengths, Weaknesses, Opportunities and threats (SWOT) analysis. the study methods and framework

are described in Figure 2. According to Figure 2, a mixed-method approach was used in the study, the mix-method included a qualitative and quantitative approaches. In the qualitative approach, secondary data from literature review and national documents were used, including stakeholder documentation across Nigeria. Also, primary data sources were considered for the quantitative approach, obtained through a stakeholders' survey through five Focused Group Discussions (FGD) and individual interviews with about 50 relevant stakeholders. Thereafter, the Strengths, Weaknesses, Opportunities & Threats (SWOT) were identified from the mixed-method approach.

The SWOT analysis explored what stakeholders considered the best and worst options and provided successful strategies for future policy development. To do this, qualitative primary data were obtained through focused group interactive sessions comprising stakeholders in the biogas sector. Insights obtained from the participatory discussions were used to design a comprehensive SWOT analysis.

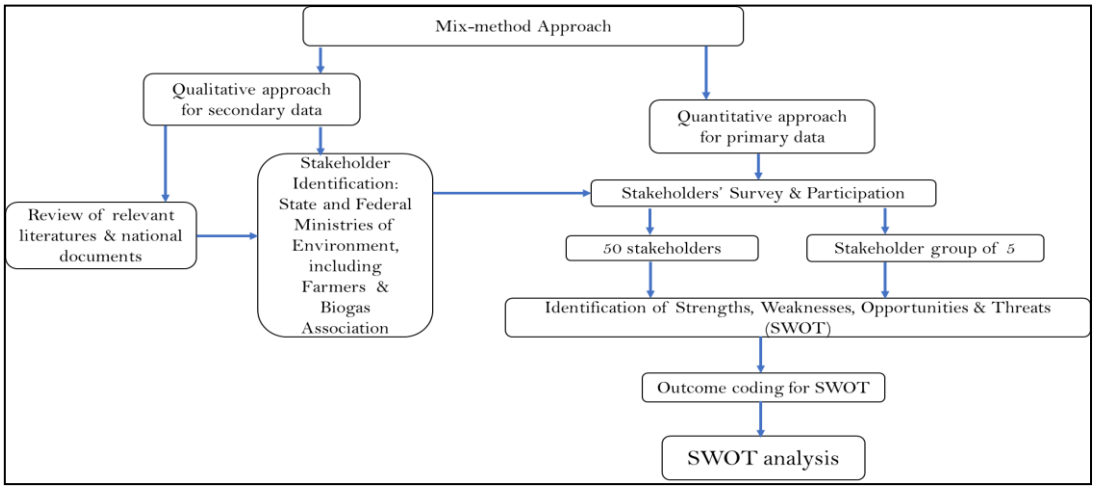

Figure 2. The study's methodological framework and data collection approach

Stakeholders' participatory framework

The concept of the participation perspective is the situated cognition approach, which emphasises how human activities are always embedded in social and cultural contexts and cannot be understood in isolation, where activities and environment are viewed as parts of a mutually constructed whole (Lipponen, 2010). Participatory research (PR) encompasses research designs, methods, and frameworks that use systematic inquiry in direct collaboration with those affected by an issue being studied for action or change (Vaughn & Jacquez, 2020)

On the other hand, the stakeholder participation framework takes the results from the identification of key social development, participation and institutional issues and

makes them a living part of a project to reduce the risks of project failure and enhance the chances of establishing a process of change that is valuable and sustainable for people over the long term (Hazeltine, 2003). On the other hand, the outcomes of participatory research and participatory modelling are increasingly adopted to assess decision-making processes. Also, outcomes from participatory modelling are significant for facilitating scientific evidence and providing supportive evidence of systems learning (Ward et al., 2015).

The stakeholder participatory modelling has been applied in diverse fields of research, including agribusiness (Purwanegara et al., 2021), energy (Shari et al., 2023), and health care (Kuziemsky et al., 2014). In a recent study, Holcomb et al. (2022) claimed that stakeholder engagement strategies play a vital role in building mutual trust, providing clear communication and valuable feedback for appropriate policy implementation. Horschig et al. (2020) used stakeholders' analysis to investigate sustainability in the German biogas sector. The study revealed that there was a need for transparent and clear rules from the government to steer sustainability in the biogas sector. Also, such an approach will communicate opportunities and yield a transparent legislation-making process for implementing a bio-economy. Similarly, Pirelli (2023) revealed that stakeholder analysis could support the adoption and establishment of innovative bioenergy value chains that yield socioeconomic and environmental benefits. Also, Xu et al. (2022)showed that stakeholder participation in farming activities will yield a better understanding of farmers' motivations, perceptions and views concerning energy use of agricultural waste and enhance the empirical basis for local energy planning towards a more sustainable energy transition. In this light, the current study will explore opportunities and barriers in the adoption of biogas from a stakeholder participatory approach.

Few studies have applied a participatory theory to investigate bioenergy adoption in the context of strengths, weaknesses, opportunities and threats (SWOT) analysis. Jaiswal1 et al. (2022), applied the SWOT analysis to investigate a clean cooking initiative that ensured access to clean cooking energy for all. Outcomes from the analysis help to develop a strategic action plan to minimize weaknesses and threats in clean cooking implementation. Similarly, A SWOT analysis revealed that biodigesters could enhance a circular economy (CE) and also identified barriers to the use of biodigesters in the context of CE (Cortez et al., 2022). However, no study has considered investigating biogas adoption and penetration into the Nigerian energy sector for national development using stakeholders' participatory techniques.

Stakeholder identification

The identification of relevant stakeholders was based on the approaches outlined in Luyet et al. (2012) and applied by Shari et al. (2023). The choice of stakeholder

identification approach was informed based on the current research context, available resources, stakeholder interest and affiliation. A stakeholder identification technique used by Shari et al. (2023) consists of identifying stakeholders by taking into account their affiliation and role in the energy sector was adopted in the current study. It also included i) stakeholder identification through review of national energy documents; ii) interest in the energy sector; iii) are directly or indirectly impacted by energy discussion; and iv) a snowball technique, which commenced with brainstorming the list of stakeholders obtained through the snowball technique. This was submitted to one of the experienced stakeholders, soliciting his opinion and allowing him to add further stakeholders.

In addition, stakeholders were identified considering several heterogeneous persons. This was practically important due to the diverse ethnicities and socio-religious affiliations in Nigeria. This approach to stakeholder identification will enable an inclusive stakeholder mix. On the other hand, the Authors have diligently excluded a few stakeholders through the identified criteria to reduce the complexity and cost of the participation process.

The identified stakeholders were selected from state and national ministries, rural women leaders, farmers' associations, energy investors, financial institutions and energy regulators. As such, about 50 stakeholders were selected. The identified stakeholders have an important affiliation and are relevant to ensuring the adoption of renewable energy technology, in this case, biogas. Table 1 shows the pool from which stakeholders were selected. It shows their affiliations, the number of stakeholders represented and their overall role. It is worth noting that the stakeholders' stated roles have important implications for biogas technology adoption and penetration in the Nigerian Energy Sector. According to Table 1, 14 institutions, including state and national ministries, rural women leaders, farmers associations, energy investors, financial institutions and energy regulators, were invited for a workshop organized in a participatory setup.

Table 1. Identification of stakeholders and their respective roles

SN	Affiliation	Number Stakeholder	Role
1	State and Federal ministry of environment	5	Coordinate state and federal affairs on environmental issues
2	Ministry of Budget	2	Provide relevant budgetary allocations
3	Federal Ministry of Power	4	To generate, distribute and transmit electricity nationwide
4	Energy Commission of Nigeria	3	To carry out overall energy sector planning and policy implementation, promote the

SN	Affiliation	Number Stakeholder	Role
			diversification of energy resources and coordinate
5	Ministry of Justice	1	Interpret and apply the Constitution
6	State and Federal Ministry of Agriculture and Food Security	5	To ensure food security in crop, livestock and fisheries, stimulate agricultural employment and services, promote the production and supply of raw materials to Agro-allied industries
7	Presidential task force on energy	2	Monitor the planning and execution of various short-term projects in generation, transmission, and distribution
8	Rural Electrification Agency	6	Encourage and promote private sector participation in rural development and enhance electricity service delivery.
9	Regulatory Agencies and system operators	2	Ensure technical and commercial conditions for access to networks and interconnections in the electricity and gas sectors
10	Commercial/financial institutions	3	Provide the investment needed in biogas technology, research and development
11	Energy Consumers Association	5	Represents consumers on issues relating to creating a sustainable energy supply, making energy costs affordable
12	Biogas Energy Developer Association	3	Oversee and facilitate biogas energy investors and biogas projects
13	Farmers Association of Nigeria	4	Considers the interest of farmers
14	Market and women leaders	3	Propagate women's integration into the biogas business in society
15	Energy Research Center	4	For Energy Research and Development in Renewable and Alternative Energy Technologies

Source: Current study

Implementation of participatory techniques

Implementing the participatory technique enabled stakeholders to share their opinions about biogas adoption irrespective of their experience and educational background.

Materials used for the stakeholders' participatory technique included clipboards, sticker notes, pens, pencils, erasers, sharpeners, temporary and permanent markers and cardboard and breadboards. Qualitative data were collected from a focused group discussion that engaged the stakeholders using the materials and methods discussed in the section.

The participatory technique involved asking the stakeholders several simple questions about biogas and the criteria for its adoption and penetration into the Nigerian energy sector. The following question guides were considered to shape the question-asking techniques.

a. What policies with strategic action plans are most relevant for biogas adoption and penetration in the Nigerian energy space?
b. what are the present and future challenges facing the adoption of biogas in the country?
c. what actions can be taken to overcome the current and future challenges in biogas penetration?
d. What are the challenges facing biogas adoption and penetration in Nigeria's energy mix?
e. what are the foreseeable enablers and barriers for upscaling bioenergy technologies towards sustainable biogas adoption in Nigeria?
f. what infrastructure development would be required to enable biogas advocacy and training?

SWOT Analysis is an analysis method used to evaluate the 'Strengths', 'Weaknesses', 'Opportunities' and 'Threats' involved in an organization, a plan, a project, a person or a business activity (Namugenyi, 2019). The SWOT analysis was used to analyse the outcomes from the stakeholders' opinions obtained from the interactive and participatory interactions (Onyekaozuoro et al., 2023). The SWOT analysis helps to assess and understand the internal and external forces/considerations that may create opportunities or risks for biogas adoption and penetration. Figure 3 shows the criteria for the SWOT assessment. According to Figure 3, the strengths and weaknesses are internally related; they are characteristics of the adoption process that give it a relative advantage and disadvantage, respectively. On the other hand, opportunities and threats are external factors. Opportunities are elements of the external environment that can be seized upon to improve biogas penetration performance; threats are realities in the greater environment, which might lead to problems for the adoption process (Teoli et al., 2023).

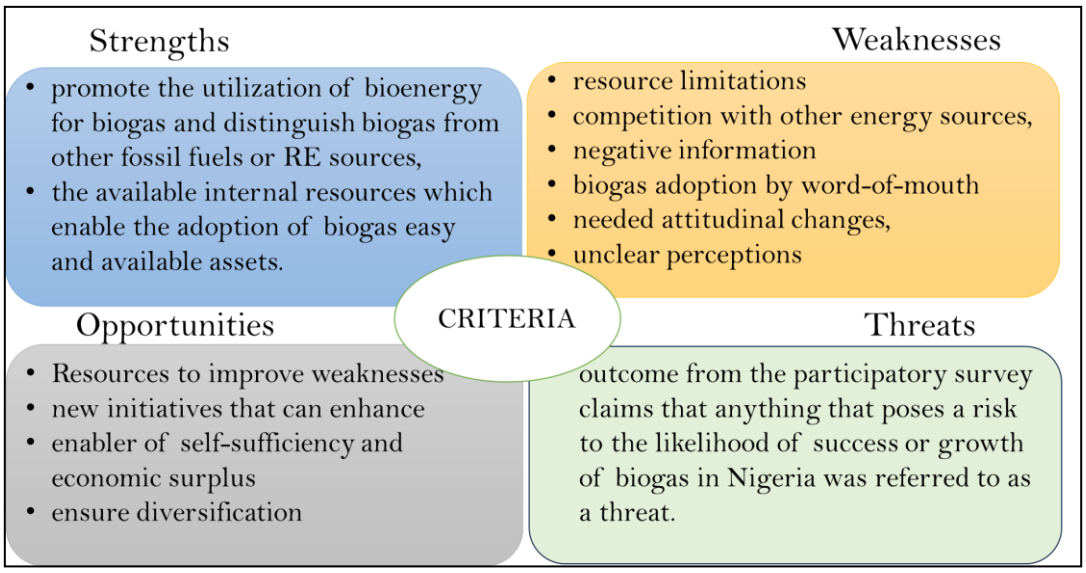

Figure 3. Criteria for SWOT analysis

Results and Discussion

Analysis of Stakeholder Landscape

Using the obtained information from the participatory survey, the stakeholder landscape revealed diverse affiliations and mandates of the participating respondents, irrespective of educational background. What was key in the stakeholder selection process was their involvement, either direct or indirect, in the bioenergy sector. Several factors were identified as internal and external constraints on the adoption of biogas in Nigeria. the categorization of the constraints was identified as either strength, weakness, opportunity or threat to the adoption process. It is also important to clarify that during the participatory dialogue, some other stakeholders (such as energy utility managers and informal waste collectors) have been overlooked in the initial selection process. The outcome from the stakeholder participatory approach to perspectives in the context of the SWOT analysis. The SWOT analysis reveals stakeholders' opinions on strengths, weaknesses, opportunities and threats of biogas adoption in Nigeria. It also identifies variables as either external or internal constraints.

Biogas adoption SWOT analysis

According to the participatory stakeholders' survey, information about biogas adoption and penetration in the Nigerian energy sector was collected and analyzed based on the SWOT analysis (Gretzky, 2010). The variables that could serve as Strengths, Weaknesses, Opportunities and Threats are coded from the information received from the participatory discussion among the stakeholders. Several participatory questions

were deliberated during the interactive seasons. The questions are geared towards identifying i) the potential qualities of biogas when compared to renewable energy sources; ii) the value and variables that the adoption of biogas lacks; iii) what biogas initiatives are underperforming and why; and iv) what potential risk factors could hinder the growth of adoption and penetration of biogas in Nigeria, among other questions for strategic planning (Benzaghta et al., 2021).

The summary of information received during the participatory survey is presented in Table 2. According to Table 2, variables presented as strengths depict qualities that promote the utilization of bioenergy for biogas and distinguish biogas from other fossil fuels or RE sources, the available internal resources which enable the easy adoption of biogas easy and available assets. The weaknesses identify issues around resource limitations (such as feedstocks and raw materials), competition of biogas to other energy sources, negative information people have concerning biogas adoption, attention to biogas tech adoption through word-of-mouth and needed attitudinal changes, including unclear perceptions of potential users and adopters could have (Igliński et al., 2016).

Resources that can be used to improve the identified weaknesses and new initiatives that can enhance the adoption of biogas are categorized as opportunities. According to Esposito et al. (2023) biogas presents a significant opportunity to enable energy self-sufficiency and economic surplus and has a singular tendency to ensure diversification of the energy supply and transform weaknesses and threats into opportunities. The outcome of the study has supported the Esposito et al. (2023) claim.

Further, the outcome from the participatory survey claims that anything that poses a risk to the likelihood of success or growth of biogas in Nigeria was referred to as a threat. This assertion supported Fernández-González et al. (2020) claim that identified threats as the variables that hinder the achievement of all possibilities of opportunities for biogas penetration. Similarly, a circular economy has been identified as a major strength and sometimes an opportunity for biogas adoption. A study from Szterlik (2021) claimed that achieving a circular economy could be threatened by other external risk factors.

In addition, in the case of strength, over 70% of stakeholders have identified that the abundant availability of feedstocks as plants and animal waste, can be leveraged to enhance biogas adoption. Also, over 71% of respondents have claimed that the adoption of biogas will address the energy gap, especially in rural areas is an opportunity for the Nigerian state, thus enhancing energy access deployed in a decentralized manner. On the other hand, weak policy and legislation were identified by many (over 80%) of the stakeholders as significant weaknesses in achieving the adoption and penetration of biogas in Nigeria. Also, major threats identified among the stakeholders included an inadequate integrated sewage system, unconscious orientation, a lack of integrated public sewage buildings and public defecation. More so, farmers' education, guaranteed

availability of feedstock at a reasonable price and secure supply of biomass of appropriate heterogeneity are reliable approaches to ensuring the sustainability of the strengths.

Table 2. The SWOT analysis for biogas adoption in the Nigerian energy sector

Strengths	Weakness
• Fixing the environment and clean air • Biogas plant requires low installation cost • Significant technical know-how • Mature technology is easy to adopt • Ability to produce a direct fuel cell • Easily deployed for meeting high domestic energy demand, e.g. cooking and heating • Readily available Indigenous biogas technicians • Available Indigenous proprietary biogas technologies • High tendency to achieve a circular economy • climate-friendly • substitute for dirty energy • Available natural gas assets can be adopted for biogas-renewable natural gas • mitigates improper waste disposal • By-product (bio-slurry) used for improving soil fertility • installation services providers abundance of Feedstock	• Lack of policy and legal framework • Lack of synergy between relevant actors • political instability • weak political will • Very few available ranching • untargeted skills • Weak available biogas infrastructure and investment • high initial cost • insufficient technical proficiency to energy demand ratio • possible resistance to novelty in new energy • low advocacy and sensitization among energy users • inadequate research and development among research institutes and universities • insufficient data on available feedstock resources • farm-gate waste • Few municipal organic wastes in rural areas Cultural and social beliefs and norms
Opportunities	**Threats**
• Addresses energy discrepancies in the rural area • encourages energy decentralization • enhances economic diversification • improves public health • skills reassignment • reduces air pollution • waste characterization/sorting • Supports energy Transition and decarbonization • Encourages a net-zero emissions plan • anaerobic digestion efficiency • creates green job opportunities • economic growth • improves social activities • enhance global collaboration on global goals of climate mitigation and technology transfer • supports climate change mitigation • supports energy security • encourages local industries • gender equity • available market for Biogas products • availability of local biogas entrepreneurs • deforestation • energy self-sufficiency and economic surplus potential source of foreign exchange	• Inadequate landfills • insufficient sensitization • Inadequate integrated and old sewage system • Improper/unconscious orientation • lack of integrated public policy • indiscriminate waste management • risk of biogas product vandalism and insecurity • open defecation • scale of operation • competitive use of raw materials and feedstock • complications in the understanding of environmental problems among citizens • initial capital cost and operation costs • Low capital means of implementing large-scale biogas production • insufficient technology Design • inadequate government support for anaerobic digester technology • Market changes and unstable economies Insufficient availability of agricultural products for both human and animal consumption

Source: current survey and outcome of the interview

Conclusion and strategic action plan

The study has used a stakeholder participatory approach to explore enablers and barriers for upscaling bioenergy technologies towards a sustainable biogas Adoption in Nigeria. To ensure renewable energy development in Nigeria, a SWOT analysis of biogas (renewable gas) has been described. Stakeholders, during the participatory interactive sessions, have identified several factors that could either be a source of support (strengths), advantageous chances/favourable conditions (opportunities) or resource limitations (weaknesses) and potential risks (threats) that could enhance or limit the adoption and penetration of biogas technologies in Nigeria. The study concludes that appropriate trade-offs and synergies among the identified barriers and enablers were necessary for a reliable measure that enhances the sustainable adoption of clean energy solutions and is complemented by appropriate strategic action plans.

The strategic action plans are a result of rigorous stakeholders' participatory discussions through the lenses of a biogas-SWOT analysis.

1. Legislate integrated buildings: such as hotels, government/public buildings, student hostels, dormitories, etc., with large numbers of occupants, have an integrated sewage system compatible with generating renewable biogas;
2. Incentivize and motivate the ranching system: Keeping domestic animals like cattle in a large space of land would enhance the generation of feedstocks for biogas;
3. Ensure deliberate awareness and biogas technologies advocacy among farmers;
4. Provide attractive incentives for bioenergy investors.
5. Ensure adequate synergy between relevant factors such as finance industries, private and public investors, consumer and manufacturing groups/associations, and government agencies;
6. Empower the research institute on research and development on renewable biogas

Table 3. Description of factors for action plan and strategy

Factors for the action plan	Action plan strategy
Penetration and adoption	Awareness creation; Affordability of the biogas products Accessibility of the biogas technology Acceptability of the biogas technology
Appropriate trade-offs and synergies	Huge national benefits, among the identified barriers and enablers. Enhancing the sustainable adoption of the clean solution
Upscaling of biogas technology	alternative clean energy/technology solution in Nigeria
Abundance of Feedstock	Curbing indiscriminate waste disposal

Source: current study

Reference

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