



From potential to practice: rethinking Africa's biogas revolution

Journal Article**Author(s):**

Kalina, Marc ; Ogwang, Jonathan Òlaj; Tilley, Elizabeth 

Publication date:

2022-10-14

Permanent link:

<https://doi.org/10.3929/ethz-b-000580783>

Rights / license:

[Creative Commons Attribution 4.0 International](#)

Originally published in:

Humanities and Social Sciences Communications 9(1), <https://doi.org/10.1057/s41599-022-01396-x>



COMMENT



<https://doi.org/10.1057/s41599-022-01396-x>

OPEN

From potential to practice: rethinking Africa's biogas revolution

Marc Kalina ^{1,2}✉, Jonathan Òlal Ogwang¹ & Elizabeth Tilley¹

The purpose of this comment is to call for more critical engagement with the potential and practice for biogas investment on the African continent. Over the past two decades, immense amounts of money have been spent by African governments, private individuals, and most conspicuously, international aid agencies and donors, on countless biogas projects in every country on the continent. Yet, despite the investments, biogas in African countries has not taken off, and the continent is strewn with the ruins of hundreds of failed and abandoned biogas projects. Moreover, scholarly literature contains little feedback about what actually happens on the ground. Drawing on this critical reading of the literature, including its blindspots on project outcomes and failures, and drawing on the authors' own extensive experience with small-scale biogas projects in Malawi and South Africa, this comment article calls for more scholarly critical reflection on why a biogas revolution, that has been perennially over the horizon, has yet to arrive while centring the role of social scientists to engage with biogas owners and operators to bridge the socio-technical divide from potential to practice.

¹ Department of Mechanical and Process Engineering, ETH Zurich, Zurich, Switzerland. ² School of Engineering, University of KwaZulu-Natal, Durban, South Africa. ✉email: Mkalina@ethz.ch

Introduction

In May 2021, a newspaper article from Kampala, Uganda made the rounds on Twitter for the wrong reasons. The story reported that a new biodigester project, located at a wastewater treatment works in the city, and funded by the state, the African Development Bank (AfDB), and the European Union (EU), would not be able to produce methane because the faecal matter generated from Kampala residents, and used by the biodigester as feedstock, did not contain the 'necessary ingredients' to produce gas (Odyek, 2021). The article quoted Dr Florence Grace Adongo, the director of water resources management in the Ministry of Water and Environment as saying "It seems that what we are eating is lacking something, the diet of the people is not producing methane.... it is not viable" (Odyek, 2021, p. 1). Although the National Water and Sewerage Corporation (NWSC), which owns the digesters, quickly disavowed the story, claiming the plants had not yet been commissioned (NWSC, 2021), Twitter users enjoyed poking fun at the story. Commentators seesawed between questioning the veracity of Dr. Adongo's claim, and positing other, underlying causes that may be responsible for the plant's failure to produce methane, such as poor construction or siting, and jokingly offering emergency supplies of high-methane producing foods as supplementary rations to Kampala residents. For many of us who have worked with, or written about biogas on the continent, who have dealt with quotidian mishaps and structural barriers or follies which often lure projects towards their inevitable, ignominious ends, the story evoked a sense of déjà vu: a missed opportunity to engage with the root causes of project failure.

Irrespective of if the Kampala report was correct or not, the tenor of the story rang true for many who have followed the history of biogas development in sub-Saharan Africa. Through a process of anaerobic digestion, biogas digesters facilitate the conversion of organic waste materials such as faecal matter, food waste, or animal dung into biogas, which is primarily composed of energy-rich methane gas (CH₄). With little to no processing, biogas can be used for cooking, lighting, or electricity generation, and has therefore been touted on the African continent for decades as a golden pathway to sustainable energy production (Ali et al., 2020; Funmi et al., 2021; Msibi and Kornelius, 2017; Surroop et al., 2019), local economic development (Lietaer et al., 2019; Mengistu et al., 2015), increased agricultural production and soil remediation (Ngumah et al., 2013; Smith et al., 2014), climate change mitigation (Bruun et al., 2014; Funmi et al., 2021; Hoch et al., 2018), decreased deforestation (Bär et al., 2021; Lietaer et al., 2019; Twinomunuji et al., 2020), reduced household and ambient air pollution (Lietaer et al., 2019; Twinomunuji et al., 2020), and as a waste management solution (Ali et al., 2020; Funmi et al., 2021; Ngumah et al., 2013; Owang et al., 2020a; Surroop et al., 2019). In chasing this dream, immense amounts of money have been spent by African governments, private individuals, and most conspicuously, international aid agencies and donors, on countless biogas projects in every country on the continent, trying to mimic the success that biogas has had in other contexts, such as China, where massive state investment has seen widespread biogas acceptance and adoption, especially in rural areas (Aamodt and Wenqin, 2013; Rupf et al., 2015). Yet, despite the investments, biogas technology has not only not spread but seems to be moving backward. Indeed, the continent is strewn with the ruins of hundreds¹ of failed, ruined, abandoned biogas projects, primarily small-scale or household size, but also on the macro-scale, serving as permanent reminders of poorly conceptualized projects and an unwillingness to critically engage with some difficult questions. (Haider, 2021). Most obviously: Why has biogas in Africa not taken off? Like in Kampala, it

cannot just be the feedstock that is wrong; rather, there must be underlying causes for failure going unaddressed.

The purpose of this comment is to shine a light on how biogas interventions have been written about and discussed, specifically within an African context. Briefly surveying contemporary biogas literature, and drawing on the authors' own extensive experience with biogas project development in Southern Africa, both as scholars critically mapping outcomes in Malawi and as biogas implementors in South Africa, we argue that the way we, as biogas practitioners talk about and internalise failure must be critically discussed, if we are to learn from the process, rather than to continue to repeat the same mistakes, if biogas in Africa is ever going to approach the potential it is continually posited to have.

Evaluating biogas: writing about failure

Although biogas has generated a tremendous amount of scholarly output, the bulk of the work that has been produced, especially on small-scale decentralised digesters, demonstrates an overwhelming tendency to focus on positives: on biogas's unlimited potential to solve several pressing global issues, while generally ignoring why this has not yet happened. Moreover, the bulk of biogas literature tends to take a high-level approach, often through reviews rather than with new empirical data, with very few case studies on specific interventions, and a tendency to focus on the limited success that has occurred with small-scale digesters, in specific contexts, with only brief speculation on why these limited successes remain so.

Although failure remains largely a taboo topic for a field that seems determined to continue to look forward, challenges *are* often discussed. Yet the discussion is usually systemic; the narrative moves through a discussion of 'barriers', from a global, regional, or national perspective, which may help to illustrate trends at a macro-level but does little to help us understand why so many projects often fail. As such, within this vast body of work, the *promise* of small-scale biogas remains, there are just several barriers preventing its actualisation: barriers that are continually discussed but rarely seem to get addressed. Specific barriers that have received significant attention include: the high initial cost of technologies, as well as the constant cost of maintenance, especially for the poor (Bekchanov et al., 2019; Chen et al., 2017; Dyah, 2019; E. U. Khan and Martin, 2016; Landi et al., 2013; Mittal et al., 2018; Puzzolo et al., 2016; Rupf et al., 2015; Taylor et al., 2019), a lack of state or donor investment in biogas, for both research and to assist with funding (Bößner et al., 2019; Boyd, 2012; Ho et al., 2015; Mukeshimana et al., 2021; Nevzorova and Kutcherov, 2019; Patinvoh and Taherzadeh, 2019; Silaen et al., 2020), as well as the inability for small plant owners to take advantage of international carbon credit schemes (Shane et al., 2015); the difficulty of accessing biogas technology within some national contexts (Hamid and Blanchard, 2018; Parawira, 2009), a lack of supportive public policy framework in certain nations (Bekchanov et al., 2019; Bößner et al., 2019; Boyd, 2012; Gao et al., 2019; Hasan et al., 2020; Ho et al., 2015; Patinvoh and Taherzadeh, 2019; Roopnarain et al., 2020; Yousuf et al., 2016), or low state or institutional capacity to implement a national biogas programme (e.g. Budiman, 2021; Landi et al., 2013; Nevzorova and Kutcherov, 2019; Rupf et al., 2015), as well as onerous regulatory barriers (Mittal et al., 2018; Taylor et al., 2019); including potential political instability in some contexts (Kamp and Bermúdez Forn, 2016), a lack of sufficient or consistently available feedstocks (Chen et al., 2017; Glivin and Sekhar, 2020; Iqbal et al., 2014; K. Khan et al., 2018; Mittal et al., 2018; Nevzorova and Kutcherov, 2019; Roopnarain et al., 2020), poor climactic conditions, including variable temperatures or water scarcity (Kamp

and Bermúdez Forn, 2016; Mittal et al., 2018; Rupf et al., 2015), space for digester installations, especially in dense village or urban contexts (Akinbami et al., 2001), labour intensity of daily operation for owners (Roopnarain et al., 2020; Silaen et al., 2020; Taylor et al., 2019), the unpredictability of biogas production and yields, which may render small-scale commercial utilisation unfeasible (Bensah et al., 2011; Owang et al., 2020b), potential cultural stigma or taboos associated with handling faecal matter or animal waste (Budiman, 2021; Dyah, 2019; Mittal et al., 2018; Rupf et al., 2015; Shane et al., 2015), market barriers which influence demand for the gas, such as competition with other available, potentially cheaper, fuel sources (Bensah et al., 2011; Mittal et al., 2018; Nevzorova and Kutcherov, 2019; Taylor et al., 2019; Zuzhang, 2013), the poor monitoring and maintenance of existing digesters (Iqbal et al., 2014; Shane et al., 2015; Taylor et al., 2019), and finally, a lack of knowledge, information, and training for potential biogas owners or installers (Bößner et al., 2019; Dyah, 2019; Hasan et al., 2020; Landi et al., 2013; Mittal et al., 2018; Patinvoh and Taherzadeh, 2019; Rupf et al., 2015; Taylor et al., 2019). Again, this body of scholarship may help form a picture as to why small-scale biogas, as an idea or larger international or national project, may have ‘failed’ to take off, but the insight they provide into why individual projects ‘fail’ is fragmentary.

Some scholars have been blunter in their handling of failure, yet, remarkably, while writing within broader national contexts, have been able to maintain their optimism about biogas, even when confronted with objective failure. For instance, Diouf and Miezan (2019), writing about Senegal, discuss the state’s biogas rollout, which promised 8000 household digesters, yet only delivered 600. Yet, even in this instance, the authors are not critical of the basic premise of the project, and, despite the failure, continue to propose alternative pathways through which the original target may be achieved. In Nepal, Lohani et al. (2021) note that although the country has built more than 430,000 small-scale digesters over the past 60 years, there has been little domestic technological development, and less than one percent of the total biogas potential has been realised, despite decades of government support and financing. Yet, like Diouf and Miezan (2019), they remain optimistic, not questioning the wisdom of further investment, but rather espousing the need for further technological development to help digesters adapt better to local conditions. However, Bruun et al. (2014) warn of the risks of failure, describing abandoned digesters as potential climate change bombs due to possible methane leaks. As such, they warn that the further proliferation of small-scale digesters may contribute significantly to global emissions of methane.

Embedded, qualitative research or individual case studies on specific biogas projects are limited, especially in comparison to the ocean of macro-level research on the topic. Yet the few studies that do exist have shed some light on why projects may experience poor outcomes after commissioning, with the technical challenges of maintaining plants in rural areas figuring prominently. For instance, Mahdi et al. (2012) used a mixed methodological approach to examine 85 digesters in Bangladesh’s Pabna District, finding that 65% were not operating or operating poorly, with most failure owing to technical complications linked to the digester or the associated appliances. Likewise, in a survey of 141 digester owners in central Vietnam, Roubik et al. (2016) found that one-third of owners had experienced serious problems, with technical challenges, such as leaks in the reactor or piping, malfunctioning of the stove, or breakdowns in anaerobic digestion featuring prominently. Furthermore, although Wamwea (2017), writing about Kenya, generally observed better outcomes, they also found that the leading cause of failure amongst sampled owners was technical issues. In all three instances, technical

challenges were compounded by the plant’s owner’s inability to deal with them, which when left unresolved, often led to plant abandonment. Finally, even in China, which is widely considered a biogas success story, Huanyun et al. (2013) point to low biogas use rates as well as underutilization of digestate as key contributors to plant abandonment by owners, while Jian (2009) describes mounting challenges associated with securing sufficient feedstock in depopulated and declining rural communities as another major, and growing, factor for plant failure. Lastly, in South Africa, Dumont et al. (2021) discuss the ‘yuck factor’ within biogas, a strong negative emotion that may lead people to withdraw from participation, which is a useful concept for examining user-faced ‘quit’ moments in biogas interventions.

Although these sources hint that there may be more substantial challenges to rural, small-scale digester development than the macro-body of the literature suggest, there remains a significant gap for further embedded research on project success and failure. How can funding and funders be more critically examined as predictor for project success or failure? How much does context matter, and to what degree do owners matter? Are more investments in biogas *always* better? Or as Bruun et al. (2014) note, should we pause and reconsider the further proliferation of small-scale digesters in light of so many poor outcomes? Regardless of how the domestic biogas industry develops, it is essential to develop a more critical body of literature and to start learning from failure, rather than being doomed to repeat it.

Conclusion: moving forward

As the literature sketch above has suggested, we know quite a bit about what biogas can do *in theory* towards poverty reduction, waste management, energy provision, etc., but have had very little qualitative feedback about what is actually happening on the ground. The potential of biogas remains, but with very few case studies on specific interventions, and a tendency to focus on limited successes while ignoring failures, there remains a lack of critical reflection towards a technology that, on the African continent, has failed to live up to expectations.

Our own research on biogas, centred on Malawi and South Africa, and dedicated to gathering rich quantitative *and* qualitative data on biogas outcomes within African countries, has produced a number of early results that have been revealing, and signal a need for further, grounded investigation. For instance, in Malawi, which superficially possesses many of the aspects often cited as precursors to a biogas revolution², countless abandoned digesters can be found dotting the landscape, and any expected biogas revolution has yet to catch fire. The initial mapping of projects, and engagement with owners, funders, and providers have suggested that the interplay and relationship between these three stakeholders is a key determinant of a project’s success or failure, with the owner being the most important factor, as their willingness and ability to engage with the systems seems directly correlated to outcomes. Our own, preliminary, on-the-ground, engagement with projects in both Malawi and South Africa suggests that owners who had better outcomes with biogas were the ones, who largely, sought it out for themselves, while owners who were more passive ‘beneficiaries’ within the intervention, generally experienced poor outcomes. Although the full extent to which donor involvement has boosted, or constrained, biogas adoption within Africa remains to be unpacked, these early findings may shine a critical light on the role of development aid in biogas provision within those contexts. However, what has become clear is a greater need for embedded, qualitative work, by critical social scientists within biogas research. Technical post-mortems of abandoned or failed systems, lead, in our experience, to a one-dimensional understanding of project success or failure. Rather, engaging with owners, through participatory, qualitative research,

which centres and interprets owner's experiences, and can identify potential points of friction between systems and users, may reveal understudied or systemic challenges within current models of biogas provision. Moreover, critical social science research, that challenges existing praxes, and evokes the kind of critical reflection that may lead to a meaningful change in practice, is necessary if biogas in Africa is ever going to approach the potential it is continually posited to have.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Received: 2 August 2022; Accepted: 4 October 2022;

Published online: 14 October 2022

Notes

- 1 Perhaps more, quantifying and mapping the scale of failure is one major research gap.
- 2 Abundant and diverse feedstock, relative water security in most parts of the country, persistent energy shortfalls and low electrification rates necessitating innovation, overreliance on firewood for domestic use which has led to severe deforestation, and finally, the attention of many international donor agencies willing to fund infrastructure projects, particularly ones with a veneer of sustainability which can serve to sop up some of the Global North's climate change guilt.

References

- Aamodt JB, Wenqin C (2013) Can the Chinese biogas experience shed light on the future of sustainable energy development. *Denver J Int Law Policy* 42:427
- Akinbami JFK, Ilori MO, Oyebisi TO, Akinwumi IO, 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](https://doi.org/10.1016/S1364-0321(00)00005-8)
- Ali MM, Ndongo M, Bilal B, Yetilmezsoy K, Youm I, Bahramian M (2020) Mapping of biogas production potential from livestock manures and slaughterhouse waste: a case study for African countries. *J Clean Prod* 256:120499. <https://doi.org/10.1016/j.jclepro.2020.120499>
- Bär R, Reinhard J, Ehrensperger A, Kiteme B, Mkunda T, Wymann von Dach S (2021) The future of charcoal, firewood, and biogas in Kitui County and Kilimanjaro Region: scenario development for policy support. *Energy Policy* 150:112067. <https://doi.org/10.1016/j.enpol.2020.112067>
- Bekchanov M, Mondal MAH, de Alwis A, Mirzabaev A (2019) Why adoption is slow despite promising potential of biogas technology for improving energy security and mitigating climate change in Sri Lanka? *Renew Sustain Energy Rev* 105:378–390. <https://doi.org/10.1016/j.rser.2019.02.010>
- Bensah EC, Mensah M, Antwi E (2011) Status and prospects for household biogas plants in Ghana—lessons, barriers, potential, and way forward. *Int J Energy Environ* 2(5):887–898
- Bößner S, Devisscher T, Suljada T, Ismail CJ, Sari A, Mondamina NW (2019) Barriers and opportunities to bioenergy transitions: an integrated, multi-level perspective analysis of biogas uptake in Bali. *Biomass Bioenergy* 122:457–465. <https://doi.org/10.1016/j.biombioe.2019.01.002>
- 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>
- Bruun S, Jensen LS, Khanh Vu VT, Sommer S (2014) Small-scale household biogas digesters: an option for global warming mitigation or a potential climate bomb? *Renew Sustain Energy Rev* 33:736–741. <https://doi.org/10.1016/j.rser.2014.02.033>
- Budiman I (2021) The complexity of barriers to biogas digester dissemination in Indonesia: challenges for agriculture waste management. *J Mater Cycles Waste Manag* 23:1918–1929. <https://doi.org/10.1007/s10163-021-01263-y>
- Chen Y, Hu W, Chen P, Ruan R (2017) Household biogas CDM project development in rural China. *Renew Sustain Energy Rev* 67:184–191
- Diouf B, Miezan E (2019) The biogas initiative in developing countries, from technical potential to failure: the case study of Senegal. *Renew Sustain Energy Rev* 101:248–254. <https://doi.org/10.1016/j.rser.2018.11.011>
- Dumont KB, Hildebrandt D, Sempuga BC (2021) The “yuck factor” of biogas technology: naturalness concerns, social acceptance and community dynamics in South Africa. *Energy Res Soc Sci* 71:101846. <https://doi.org/10.1016/j.erss.2020.101846>
- Dyah S (2019) Biogas development: Dissemination and barriers. Paper presented at the IOP Conference Series: Earth and Environmental Science. Vol 277. 1–2 November 2018, Tangerang, Indonesia
- Funmi AE, Suleiman MA, Deborah OI, Dorcas AT (2021) Biogas production as energy source and strategy for managing waste and climate change. *SN Appl Sci* 3(1):1–11. <https://doi.org/10.1007/s42452-020-03973-8>
- Gao M, Wang D, Wang H, Wang X, Feng Y (2019) Biogas potential, utilization and countermeasures in agricultural provinces: a case study of biogas development in Henan Province, China. *Renew Sustain Energy Rev* 99:191–200. <https://doi.org/10.1016/j.rser.2018.10.005>
- Glavin G, Sekhar SJ (2020) Waste potential, barriers and economic benefits of implementing different models of biogas plants in a few Indian Educational Institutions. *BioEnergy Res* 13(2):668–682. <https://doi.org/10.1007/s12155-019-10073-y>
- Haider S (2021) Is there renewed hope for biogas projects in South Africa? *ESI Africa*. <https://www.esi-africa.com/industry-sectors/future-energy/is-there-renewed-hope-for-biogas-projects-in-south-africa/>
- Hamid RG, Blanchard RE (2018) An assessment of biogas as a domestic energy source in rural Kenya: developing a sustainable business model. *Renew Energy* 121:368–376. <https://doi.org/10.1016/j.renene.2018.01.032>
- Hasan ASMM, Kabir MA, Hoq MT, Johansson MT, Thollander P (2020) Drivers and barriers to the implementation of biogas technologies in Bangladesh. *Biofuels* 13(5):643–655. <https://doi.org/10.1080/17597269.2020.1841362>
- Ho TB, Roberts TK, Lucas S (2015) Small-scale household biogas digesters as a viable option for energy recovery and global warming mitigation—Vietnam case study. *J Agric Sci Technol* 5:387–395. <https://doi.org/10.17265/2161-6256/2015.06.002>
- Hoch S, Friedmann V, Michaelowa A (2018) Mobilising private-sector investment to mitigate climate change in Africa. Stockholm Environment Institute. Retrieved at <https://www.jstor.org/stable/resrep17204>
- Huanyun D, Rui X, Jianchang L, Yage Y, Qiuxia W, Intekhab Hadi N (2013) Analysis on sustainable development countermeasures and barriers of rural household biogas in China. *J Renew Sustain Energy* 5(4):043116. <https://doi.org/10.1063/1.4816690>
- Iqbal SA, Rahaman S, Yousuf A (2014) Present scenario of biogas technology in Bangladesh—prospects, potentials and barriers. In: Proceedings of the 15th annual paper meet, 7–8 February 2014, Dhaka, Bangladesh
- Jian L (2009) Socioeconomic barriers to biogas development in rural Southwest China: an Ethnographic Case Study. *Hum Organ* 68(4):415–430. <https://doi.org/10.17730/humo.68.4.y21mu5t8075t881>
- 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>
- Khan EU, Martin AR (2016) Review of biogas digester technology in rural Bangladesh. *Renew Sustain Energy Rev* 62:247–259. <https://doi.org/10.1016/j.rser.2016.04.044>
- Khan K, Rahman ML, Islam MS, Latif MA, Khan MAH, Saime MA, Ali MH (2018) Renewable energy scenario in Bangladesh. *IJARII* 4(5):270–279
- Landi M, Sovacool BK, Eidsness J (2013) Cooking with gas: policy lessons from Rwanda's National Domestic Biogas Program (NDBP). *Energy Sustain Dev* 17(4):347–356. <https://doi.org/10.1016/j.esd.2013.03.007>
- Lietaer S, Zaccai E, Verbist B (2019) Making cooking champions: perceptions of local actors on private sector development in Uganda. *Environ Dev* 32:100452. <https://doi.org/10.1016/j.envdev.2019.07.002>
- Lohani SP, Dhungana B, Horn H, Khatiwada D (2021) Small-scale biogas technology and clean cooking fuel: assessing the potential and links with SDGs in low-income countries—a case study of Nepal. *Sustain Energy Technol Assess* 46:101301. <https://doi.org/10.1016/j.seta.2021.101301>
- Mahdi TH, Hasib ZM, Ali M, Sarkar MAR (2012) An aspect of biogas plants at Pabna district in Bangladesh. Paper presented at the 2nd International Conference on the Developments in Renewable Energy Technology (ICDRET 2012), 5–7 January 2012
- Mengistu MG, Simane B, Eshete G, Workneh TS (2015) 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>
- Mittal S, Ahlgren EO, Shukla PR (2018) Barriers to biogas dissemination in India: a review. *Energy Policy* 112:361–370. <https://doi.org/10.1016/j.enpol.2017.10.027>
- Msibi SS, Kornelius G (2017) Potential for domestic biogas as household energy supply in South Africa. *J Energy South Africa* 28(2):1–13. <https://doi.org/10.17159/2413-3051/2017/v28i2a1754>
- Mukeshimana MC, Zhao ZY, Ahmad M, Irfan M (2021) Analysis on barriers to biogas dissemination in Rwanda: AHP approach. *Renew Energy* 163:1127–1137. <https://doi.org/10.1016/j.renene.2020.09.051>

- Nevzorova T, Kutcherov V (2019) Barriers to the wider implementation of biogas as a source of energy: a state-of-the-art review. *Energy Strateg Rev* 26:100414. <https://doi.org/10.1016/j.esr.2019.100414>
- Ngumah C, Ogbulie J, Orji J, Amadi E (2013) Potential of organic waste for biogas and biofertilizer production in Nigeria. *Environ Res Eng Manag* 63(1):60–66. <https://doi.org/10.5755/j01.erem.63.1.2912>
- NWSC [@nwscug]. (2021). Dear Sam, this info is not true [Twitter]
- Odyek J (2021) Kampala's human waste fails to produce electricity. *NewVision*. Retrieved from <https://www.newvision.co.ug/article/details/102892>
- Ogwang JO, Kalina M, Mahdjoub N, Trois C (2020a) Integrated biogas systems as rural sanitation solutions: reflections from five institutional interventions in Ndwedwe, KwaZulu-Natal. Paper presented at the Water Institute of South Africa 2020 Online Conference, 7–11 December 2020
- Ogwang JO, Kalina M, Jegede A, Mahdjoub N, Trois C (2020b) The development of an optimised small scale anaerobic digester design for rural South African areas. Paper presented at the 8th International Symposium on Energy from Biomass and Waste (Venice 2020), 16–19 November 2020
- Parawira W (2009) Biogas technology in sub-Saharan Africa: status, prospects and constraints. *Rev Environ Sci Bio/technol* 8(2):187–200. <https://doi.org/10.1007/s11157-009-9148-0>
- Patinvoh RJ, Taherzadeh MJ (2019) Challenges of biogas implementation in developing countries. *Curr Opin Environ Sci Health* 12:30–37. <https://doi.org/10.1016/j.coesh.2019.09.006>
- Puzzolo E, Pope D, Stanistreet D, Rehfuess EA, Bruce NG (2016) Clean fuels for resource-poor settings: a systematic review of barriers and enablers to adoption and sustained use. *Environ Res* 146:218–234. <https://doi.org/10.1016/j.envres.2016.01.002>
- Roopnarain A (2020) Biogas technology in Africa: an assessment of feedstock, barriers, socio-economic impact and the way forward. In: Balagurusamy N, Chandel AK (eds) *Biogas Production*. Springer, Cham. pp. 415–445
- Roubik H, Mazancová J, Banout J, Verner V (2016) Addressing problems at small-scale biogas plants: a case study from central Vietnam. *J Clean Prod* 112:2784–2792. <https://doi.org/10.1016/j.jclepro.2015.09.114>
- 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. *Renew Sustain Energy Rev* 52:468–476. <https://doi.org/10.1016/j.rser.2015.07.107>
- Shane A, Gheewala SH, Kasali G (2015) Potential, barriers and prospects of biogas production in Zambia. *J Sustain Energy Environ* 6:21–26
- Silaen M, Taylor R, Bößner S, Anger-Kraavi A, Chewprecha U, Badinotti A, Takama T (2020) Lessons from Bali for small-scale biogas development in Indonesia. *Environ Innov Soc Transit* 35:445–459. <https://doi.org/10.1016/j.eist.2019.09.003>
- Smith J, Abegaz A, Matthews RB, Subedi M, Orskov ER, Tumwesige V, Smith P (2014) What is the potential for biogas digesters to improve soil fertility and crop production in Sub-Saharan Africa. *Biomass Bioenergy* 70:58–72. <https://doi.org/10.1016/j.biombioe.2014.02.030>
- Surroop D, Bundhoo ZMA, Raghoo P (2019) Waste to energy through biogas to improve energy security and to transform Africa's energy landscape. *Curr Opin Green Sustain Chem* 18:79–83. <https://doi.org/10.1016/j.cogsc.2019.02.010>
- Taylor R, Devisscher T, Silaenb M, Yuwono Y, Ismail C (2019). Risks, barriers and responses to Indonesia's biogas development. Stockholm Environmental Institute. <https://cdn.sei.org/wp-content/uploads/2019/05/indonesia-biogas-development.pdf>
- Twinomunji E, Kemausuor F, Black M, Roy A, Leach M, Sadhukhan ROJ, Murphy R (2020) The potential for bottled biogas for clean cooking in Africa. *Modern Energy Cooking Services (MECS)*, Surrey, UK
- Wamwea SN (2017) Success and failure of biogas technology systems in rural Kenya: an analysis of the factors influencing uptake and the success rate in Kiambu and Embu counties. Masters Thesis in International Development Studies. Norwegian University of Life Sciences, Ås
- Yousuf A, Khan MR, Pirozzi D, Ab Wahid Z (2016) Financial sustainability of biogas technology: barriers, opportunities, and solutions. *Energy Sources Part B: Econ Plan Policy* 11(9):841–848. <https://doi.org/10.1080/15567249.2016.1148084>
- Zuzhang X (2013) Domestic biogas in a changing China: Can biogas still meet the energy needs of China's rural households. London: International Institute for Environment and Development (IIED)

Competing interests

The authors declare no competing interests.

Ethical approval

This research was approved by the National Committee On Research in The Social Sciences And Humanities (NCRSH) in Malawi, Protocol No. P.03/21/560. The study was performed in accordance with relevant guidelines/regulations applicable to research with human participants, per NCRSH standards and guidelines.

Informed consent

Written informed consent was obtained from all participants for participation in the study.

Additional information

Correspondence and requests for materials should be addressed to Marc Kalina.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2022