THE SUDD INSTITUTE
RESEARCH FOR A PEACEFUL, JUST AND PROSPEROUS SOUTH SUDAN

P. O. Box 34, Juba, South Sudan • Tel: +211 (0)956 305 780
Email: thesudd.institute@gmail.com • www.suddinstitute.org

Policy brief

March 21, 2024

Valorization of Organic Waste through Anaerobic Processes: An Opportunity for South Sudan

Nhial Deng Nhial KAMOT

Summary

Anaerobic technology is a biotechnological intervention that has been employed for decades to treat organic waste streams producing methane-rich biogas as a significant energy carrier capable of being turned into electricity and heat. Biogas is an important component of the green energy sources which could partially solve energy crisis in different parts of the world. The debate about biogas from anaerobic technologies has been recently reignited because of its validity in the contexts of both developed and developing countries. In South Sudan, there is a major energy challenge which requires diversification of energy sources. Firstly, there is an overdependence on charcoal as the energy source for cooking, with about 96% of the population utilizing it for cooking. Not only does charcoal production lead to destruction of forest resources but its combustion also causes unhealthy smoke which affects the respiratory system of end users. Secondly, there is only 5.4% of the population nationwide that has access to electricity. To ensure that energy sources are sustainably diversified and to meet Sustainable Development Goal (SDG 7) of ensuring access to affordable, reliable, sustainable, and modern energy for all, there is a need to employ anaerobic digestion to generate biogas that can be used for cooking and lighting in homes and commercial places alike. The International Organization of Migration (IOM) has successfully initiated a pilot project at Malakal Protection of Civilians (PoC) site, which produces 4 m^3/day of biogas capable of powering 4 households daily. This intervention clearly shows that biogas production is practically possible and could be a viable way of generating alternative energy. Experiences from neighboring Kenya and Uganda demonstrate that anaerobic digestion could be a plausible way to sustainably increase South Sudan's energy mix.

Considering the above, the following recommendations are presented:

- *Formulation of policies and regulations that encourage financial institutions to offer loans for investment in anaerobic digestion technology.*
- *There is a need to develop South Sudan Biogas Program that can be funded by government, donors, and development partners such as the Dutch Government and private sector.*
- *There should be a constructive partnership between the government and partners like IOM for sharing of experiences regarding biogas production.*
- *There should be rigorous research on biogas production to inform national policies and interventions.*

1. Introduction

While global consumption of non-renewable energy resources has increased over the years, the discovery and production of these resources are dwindling (Agler et al., 2011). To combat this potential crisis, nations and international agencies have embarked on a transition to green economy (Bina, 2013). This transition can be achieved through the adoption of new technologies, including biobased technologies which valorize materials from wastes, thus fostering circularity of materials and enhancing sustainable development (Jha & Kumar, 2019). Most typical biobased technologies involve anaerobic processes which occur in oxygen-deficient environments. Anaerobic processes have been employed over the years for the recovery of resources from waste materials. Chief among these technologies is anaerobic digestion which yields energy-rich methane and digestate which is rich in nitrogen and phosphorous (Greses et al., 2021).

Anaerobic digestion (AD) is a widely recognized environmentally friendly technology that has been used over the years as one of the treatment technologies for stabilizing organic materials and/or wastewater producing energy-rich end-product and nutrients-rich liquid digestate (Kleerebezem et al., 2015). This technology has been employed to tackle wastes from diverse sources such as streams with high solid content (e.g., slaughterhouse wastes, livestock manure, sewage sludge, food waste, municipal solid waste, agricultural waste, energy crops, and algal biomass), as well as wastewaters with mostly soluble organic carbon (e.g., agro-industrial wastewater, sewage, and chemical industrial wastewater) (Kleerebezem et al., 2015).

As the name suggests, anaerobic digestion utilizes anaerobic bacteria to degrade organic matter in the absence of oxygen. Contrary to aerobic processes that require massive energy for their operations, anaerobic processes are less energy intensive but lend maximum energy output. As a result, they are commonly employed as self-sufficient waste treatment technologies to both treat organic wastes and to generate valuable biogas and nutrients-rich digestate (Kumar & Samadder, 2020).

There are other alternative biobased anaerobic technologies such as anaerobic fermentation for the better valorization of organic waste (Kleerebezem et al., 2015). This technology produces important added-value outputs such as short-chain volatile fatty acids (VFAs), alcohols, and energy-carrying hydrogen gas (H_2) which have wide industrial applications with the added advantage of low greenhouse gas emissions compared to methane production (Kleerebezem et al., 2015). Anaerobic fermentation process falls within the carboxylate platform, which is a biorefinery platform after sugar and thermochemical platforms (Holtzapple & Granda, 2009.). In the carboxylate platform, the undefined mixed culture process generates a mixture of carboxylates (short-chain VFAs such as acetate, propionate, lactate, and n-butyrate) during primary fermentation (Agler et al., 2011). These carboxylates are frequently used as substrates for secondary fermentation reactions in the same undefined mixed culture, or they can be processed separately in pure-culture biochemical, electrochemical, and thermochemical steps to produce bulk bioproducts, such as high-volume fuels or industrial solvents (Agler et al., 2011).

Anaerobic technologies that produce biogas and digestate have been widely used globally in the context of both energy and agricultural production. In 2011, biogas accounted for 27% of the global biofuel market demand and about 0.25% of the global energy market (Hahn, 2015). It is expected that this number has increased given significant investments in biogas production facilities for the last decade. With the current interest of nations to further their transition to green energy and with the perceived potential of biogas production globally, biogas will become even more critical in the 21st century. Recently, Rwanda built a pilot bio-digester in a prison infrastructure the produced biogas accounting for 50% of all the cooking energy needs in the prison facility (Phuangpornpitak and Tia, 2013). It is envisioned that in the face of global energy crisis, biogas will play a crucial role in answering the energy call for developing countries.

South Sudan faces an enormous challenge in terms of its waste management and energy demand. Thus, employing anaerobic technologies can be a suitable way of tackling the waste crisis that has engulfed the country. This way, the country would be able to address, in a single package, its waste management challenge, and to diversify its energy sources for consumption in the local market. This Policy Brief, therefore, seeks to explain the benefits that can be obtained from adopting policies and programs that foster investment in alternative energy sources, such as biogas from anaerobic digestion. Light emphasis will be made on emerging anaerobic technologies such as anaerobic fermentation.

2. Importance of Anaerobic Processes in South Sudan

2.1. Current energy status in South Sudan

Currently, communities in South Sudan employ unsustainable energy generation practices. Chief among these is uncontrolled cutting of trees for charcoal production. Charcoal remains a major cooking fuel in South Sudan for at least 96% of households (Tiitmamer & Anai, 2018). This overdependence on charcoal as a source of energy presents a serious threat to natural forest, which serves as a carbon sink and rain generator through evapotranspiration. A survey conducted jointly by United Nations Environment and the Government of South Sudan in 2015 found that the cooking fuel demand for Juba City alone translated to a cutting of an estimated five million trees[1]. This results in an annual deforestation rate of between 1.5% and 2%, leading to serious dwindling of natural forest which is an inevitable catalyst for rainfall variabilities.

Not only does unregulated logging of trees lead to environmental degradation, but it also disrupts natural ecosystems and affects the natural ecology. This challenge necessitates interventions that could generate alternative fuel sources whose utilization will alleviate the pressure on natural forest and reduce uncontrolled logging of trees for charcoal production. Conversely, the energy needs for electrification are massively overwhelming as only 5.4%

[1] UNEP. (2018). South Sudan cracks down on charcoal trade
https://www.unep.org/news-and-stories/story/south-sudan-cracks-down-charcoal-trade

of South Sudanese population has access to electricity[2]. Majority of this electricity is supplied off-grid using solar sources accounting for about 3.44% of the population that has access to electricity. According to this report, the total installed power capacity in South Sudan was 103 MW in 2022, which is way below the projected national electricity demand of 800 MW in the same year. JEDCO, which is the main electricity distributor in Juba, supplies only 33 MW of electricity which serves only 20% of the population in the city. Many unserved citizens resort to solar sources and diesel generators for their electricity needs. It is evident that meeting the current projected electricity demand in South Sudan will require extensive efforts from South Sudan government and perhaps extensive exploration of other electricity options.

As the challenges of charcoal usage for heating and cooking and solar panels usage for electrification are persistent, there is a need to explore alternative energy sources such as biogas.

2.2. Status of biogas as an alternative energy in South Sudan

Biogas as an alternative energy source is not sufficiently utilized in South Sudan now, either for cooking or electrification purposes. To the best of author's knowledge, alternative energy production has been exploited mostly by humanitarian entities in South Sudan. The case in point is a pilot project currently in operation by IOM in Malakal Protection of Civilians (PoCs) site where the agency constructed an anaerobic biodigester for simultaneously treating fecal sludge and producing biogas[3]. In this pilot project, fecal sludge from female toilet of 10 latrines is fed to an anaerobic biodigester, producing an average of $4m^{3}$/day biogas, which is used for cooking by 4 households daily and the lighting of the said latrines. The use of biogas from this anaerobic biodigester for cooking and lighting purposes not only meets the energy needs of the internally displaced South Sudanese in the Malakal PoC site but also saves 9.4–11.4 tons of firewood use for cooking per year, according to the report[3]. Therefore, developing and expanding alternative energy sources, particularly biogas production, could be an important step towards both enhancing the sanitation situation and diversifying energy mix in the country.

Although adopting anaerobic technology could be akin to killing two birds with one stone (energy needs and sanitation), its implementation does not go without its challenges. One of the most important challenges is limited financing. Anaerobic biodigesters require high initial financial investment although the subsequent operational cost is relatively low. This poses a major challenge as developing countries like South Sudan have limited resources to invest in capital-intensive projects of this nature. Secondly, undeveloped infrastructure is another crucial barrier in large-scale transition to anaerobic technology. Availability of stable electricity and well-connected water, and wastewater network are crucial for efficient implementation of anaerobic technology. These infrastructures are highly lacking in South

---

[2] ESMAP., World Bank., Sudd Institute., EED Advisory (2023). Pathways to electricity access expansion in South Sudan: Off-grid and mini-grid market assessment. Report.

[3] South Sudan Green initiatives in WASH – Biogas (2021) https://southsudan.iom.int/sites/g/files/tmzbdl1046/files/documents/IOM%20South%20Sudan%20-%20WASH%20Biogas%20Brief%202021_0.pdf

Sudan, posing another important setback for widespread implementation of this technology. Thirdly, socio-cultural barriers would be another significant challenge that may affect easy reception of this technology. While the government may have hard time understanding the immediate economic benefits of the technology, the average citizenry may find it difficult to accept the fact that their foods will be cooked with a gas that basically comes from fecal sludge. This obstacle requires country-wide awareness and sensitization which is unlikely within the current context of South Sudan.

2.3. Experiences from Kenya and Uganda and lessons learned

Kenya is among the first countries in Africa to adopt biogas technology in the early 1950's[4]. Out of realizing the importance of energy for economic development, Kenya massively embarked on biogas production, recording a historic construction of over 18,000 biodigesters since the adoption of the Kenya Biogas Program in 2009[5]. Although many of the anaerobic plants were successfully constructed thanks to donors and partners, Kenya, through its 2006 Energy Policy, promoted domestic and institutional biogas production by encouraging micro finance institutions to offer favorable credit terms to Kenyans who plan to have biodigesters in their farms or institutions. The major aim of this policy is to ensure that every Kenyan has access to energy for cooking, heating, and electrification, reducing the cutting of trees for firewood and charcoal. The Kenyan National Domestic Biogas Program (KENDBIP) aims at biogas production for domestic consumption. The program benefits from strong collaboration with organizations which provide technical support to ensure that quality biogas facilities are built and operated. Of importance is the financing model which tasks Kenyan National Federation of Agricultural Producers (KENFAP – a collaborating institution) to seek for funds from financial institutions on behalf of the end users. These loans or credits, once secured, are given to the end users to fund their biogas production initiatives. The approach helps in availing much needed resources to expand this biogas program.

Similarly, Uganda through its Uganda Domestic Biogas Program, rigorously leapfrogged its anaerobic technology adoption initiative constructing over 9,000 biodigesters since the inception of the said program in 2009[6]. The model applied by Uganda in fast-tracking its quest for alternative energy is similar to the one applied by Kenya, in that it involves partnership with rural cooperatives to provide loans for the setting up of the anaerobic digesters. This approach encourages investment in small scale anaerobic digesters which are cheaper to implement, compared to anaerobic plants used for treatment of fecal sludge in municipal wastewater systems. Uganda implements the same financing model which was adopted by Kenya in securing credits and loans for end users. These policy tools can be

---

[4] UNEP (2018). South Sudan cracks down on charcoal trade. (Story)
https://marketplace.goldstandard.org/products/kenya-biogas-programme

[5] Matoke.S. Biogas Energy Status in Kenya (Power point presentation)
https://www.fao.org/fileadmin/user_upload/energy/investa/presentations/PPT_Matoke.pdf

[6] 6. Gold Standard (2021). Biogas for Better Life Uganda.
https://marketplace.goldstandard.org/products/fairclimatefund-biogas-for-better-lifeuganda#:~:text=The%20Uganda%20Domestic%20Biogas%20Programme,providers%20for%20after%20sales%20services

replicated in South Sudan if the efforts to diversify energy sources are to be made a reality. Although specific numbers as to the contribution of biogas to the overall energy mix of these two countries are not available, it is believed that these biogas initiatives are helping electrify many citizens and reducing burdens on the forests.

What is strikingly clear from these two countries is that they both largely use anaerobic digesters which are generally fed with livestock's waste and agricultural biomass and in which South Sudan is rich. The key lesson from the experiences of these two countries is the government policy that encourages financial institutions to offer loans to local business owners in the private sector. Since the installation capital of anaerobic digesters is often high, these loans tend to cover this capital investment, giving owners sufficient time to repay back their loans. Another critical lesson is the political will of the governments of the two countries, which prioritize energy agenda for their countries, leading to investment on their part and bilateral cooperation with their partners such as the Dutch Government, which has been instrumental in promoting the alternative energy agenda in the two countries.

Lastly, contracting private companies through a transparent bidding process also sped up the achievement of the objectives of biogas program of these respective countries as the government only performs the regulatory/supervisory, monitoring, and evaluation roles for the implementing company.

2.4. Charcoal or biogas

The debate against charcoal product has been on the resulting destruction of forest resources and the negative health impacts on the respiratory systems of the users, among others. Although these are valid points and necessitate renewable interventions like biogas production, the question of feasibility of biogas production and consumption is crucial to be addressed. In respect to Kenya and Uganda, biogas has not been sufficiently commercialized. Anaerobic digesters established in big farms are primarily used to cater to the farm energy needs, with hardly any surplus to be commercialized or sold to cover energy demands in the market. However, Masaai Group—an enterprise in Kenya—sells biogas produced from the anaerobic digestion of waste from slaughterhouse. At $8 per 6-kilogram cylinder, the cost is half the price of Liquefied Petroleum Gas (LPG) and relatively lower than the price of charcoal[7]. There is no available data for biogas commercialization in Uganda and South Sudan, nonetheless. Even though charcoal is readily available and most common, exploring the potential of biogas is crucial for actualizing SDG 7 of achieving affordable, reliable, sustainable, modern, and clean energy for all by 2030.

2.5. Way forward

The setting-up of mini-anaerobic installations in different parts of the country, like the one established by IOM in Malakal PoC[3] site, could catalyze transition out of the charcoal

[7] Yale Environment 360. (2015). Maasai Group Plans to Sell Biogas Made from Slaughterhouse Waste.
https://e360.yale.edu/digest/maasai_group_plans_to_sell_biogas_made_from_slaughterhouse_waste

production and firewood overdependence. The biogas produced from these mini-anaerobic installations can be sold to local population as an alternative cooking fuel, replacing charcoal. This way, it can be an important component of South Sudan's energy mix.

In the developed world, anaerobic digesters, as they are often called, have incorporated energy conversion systems that convert generated biogas into electricity. This requires a more advanced technical setup which may be difficult to implement in developing countries like South Sudan, given the infrastructural challenges. However, it is possible to install small anaerobic digesters that will have gas storage chambers where the gas can be stored and sold to the local population in small plastic bags at affordable prices or connected to several families in pipes for cooking and lighting purposes **(Figure 1).** This approach creates jobs for local people and helps in preventing environmental degradation caused by unregulated cutting of trees. The main question will be the raw materials that will be needed for continuous functioning of these mini-anaerobic plants.

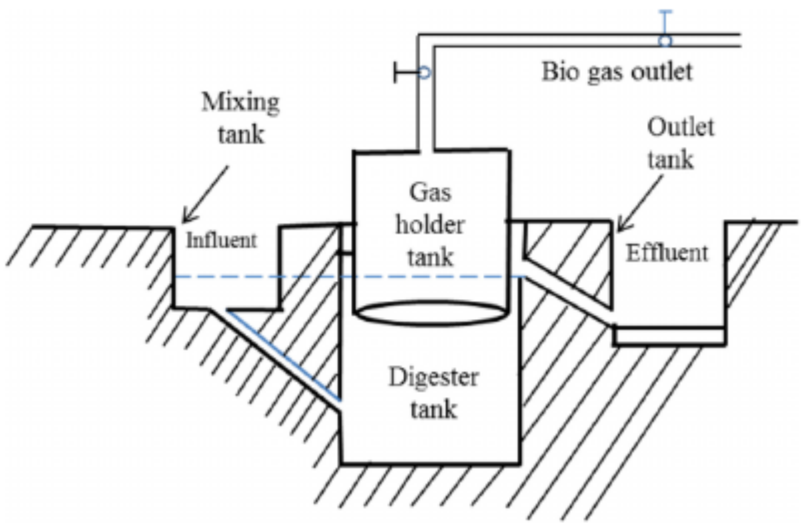

Figure 1. A set-up of mini-anaerobic digester similar to the one established by IOM in Malakal PoC (Rahman et al, 2017)

There is massive biomass that exists in different parts of the country. Some of this biomass comes from agricultural plantations that are operated in the towns' outskirts. There is a huge potential that this biomass presents, especially in the context of alternative biogas energy production. Unfortunately, majority of agricultural biomass is either burnt or discarded without proper use. If there are small anaerobic installations in different parts of the country, this massive resource could be put to an appropriate use, producing biogas which is a competitive energy source that could be used as an alternative to charcoal and as digestate, which is a nutrient-rich fertilizer for crops production. Another important anaerobic process that would use this biomass could be pyrolysis. Through this process, biomass can be converted into biochar and bio-oil[8]. Biochar is an important charcoal-alternative which could be used as a cooking fuel.

Another suitable source of raw material for anaerobic installations would be biomass from the forest. Local population living in rural areas depend on burning of grasses and other vegetation in the forest as a security tool to ease their activities in the forest such as cutting of thatch and collecting of wild fruits. Burning of forest is another practice that causes havoc to the ecological systems in the forest. According to Global Forest Watch[9], South Sudan has lost 697 ha of tree cover between 2001 and 2022 due to fires. This figure accounts for only trees destroyed and excludes the overall vegetation destruction that has occurred during this period.

The implications of these actions are dire on the animal ecosystems, generally posing irredeemable harm to the overall benefits that can be obtained from forest resources. Therefore, there is a need to create an awareness to the local population on the disadvantages of rampant burning of forest. Perhaps the best way to encourage the local people to avoid burning of forest would be to create opportunities that ensue from operationalization of small anaerobic installations.

Instead of burning grassy vegetation, they would be encouraged to cut and sell it to these anaerobic installations to be used as a raw material. In so doing there should be incentives availed to local people to prioritize alternative energy sources. As indicated above, adopting anaerobic technology could lead to a positive U-turn from terrible practices such as forest burning and unsustainable charcoal production. Quelling these practices as a result, would be a promising step towards restoring natural abundance and ecological balance. Additionally, this technology would create a synergistic effect that can spill to other sectors such fecal waste management.

Another crucial raw material for biogas production is livestock's waste. The excretory waste from livestock is a rich raw material for biogas production which is still untapped in developing countries. Only Kenya, at the moment, exploits this valuable resource to generate biogas and digestate for farm application. South Sudan's rich livestock endowment, ''with an estimated 12 million cattle, 12.1 million sheep and 12.4 million goats''[10], positions it as a global leader in animal wealth. This statistic is encouraging, as massive waste from these livestock could be converted into valuable biogas through anaerobic technology. The challenge would be the nature of keeping these livestock as many of them are moved by owners from place to place for pasture and water. It is hoped that a transformation in animal keeping practices (or encouraging herders to dry animal

---

8 Biochar for sustainable soils. What is Biochar?
https://biochar.international/the-biochar-opportunity/what-is-biochar/

9 Weekly fire alerts in South Sudan.
https://www.globalforestwatch.org/dashboards/country/SSD/?category=fires

10 FAO in South Sudan (2021). Beyond prestige: FAO Livestock Show in Kuajok promotes commercialization of cows, sheep and goats.
https://www.fao.org/south-sudan/news/detail-events/ar/c/1456968/

waste and store it for sale) and a paradigm shift in perception of alternative energy would be critical to increasing biogas production from livestock waste.

Management of fecal waste is another important challenge that South Sudan continues to face, although it is a key point of SDG 6 to supply clean and safe water, and to provide safe sanitation by 2030. However, due to limited funds, the country cannot afford Wastewater Treatment Plants (WWTPs) which are often expensive to install and operate. Thus, anaerobic treatment systems, which are often cheaper compared to aerobic systems, serve as viable technologies that could be adopted as sanitary options for fecal waste management. Roton Wastewater Lagoon[11], Bentiu Wastewater Stabilization Ponds[12], and Malakal PoC site anaerobic digesters are examples of the said anaerobic technologies.

Proper operation and upgrading of these facilities could be the first step in enhancing fecal sludge management. Facilities such as Roton Wastewater Lagoon and Bentiu Wastewater stabilization ponds could be upgraded in a manner that can both serve as fecal waste treatment zones as well as biogas production units. As such, there is significance in policy formulation to ensure that waste management and resource (energy) recovery from waste materials are an inseparable agendum.

Similarly, infrastructural upgrading could also open doors for technical adjustments in these systems. For instance, anaerobic digestion process could be shortened to only anaerobic fermentation, producing essential alcohols and volatile fatty acids which are critical for industrial applications. Therefore, anaerobic processes could be viable options that could encourage transition to green economy. In terms of practicality of implementing anaerobic processes, anaerobic digestion and pyrolysis would be easy to set up and to operate, compared to anaerobic fermentation processes. It is also straightforward to use biogas and biochar, compared to metabolites from anaerobic fermentation which must be further processed in secondary processes in order to obtain useful end-products. As such, anaerobic digestion and pyrolysis are practically feasible and beneficial in the context of South Sudan.

3 Conclusion and recommendations

The significance of adopting anaerobic processes has been addressed in this paper. The most important aspect is the valorization of organic waste to produce green energy (biogas) which is a suitable alternative to charcoal. This presents a viable opportunity for reducing rampant deforestation which has engulfed the country. Reduced deforestation preserves the health of natural ecosystems. Additionally, popularizing anaerobic digestion processes re-channels efforts bent on bad practices such as forest burning into positive actions such as cutting and selling of forest biomass (grass and seasonal biomass) for biogas production.

---

11 USAID and SUWASA. (2015). Assessment of Roton wastewater lagoon in Juba. https://www.globalwaters.org/sites/default/files/juba-wastewater-assessment-suwasa.pdf

12 Emergency Faecal Sludge Management – Lime Treatment, Bentiu, South Sudan. Octopus Case Study (2024). https://sanihub.info/wp-content/themes/gto-theme/temp_pdf/emergency-faecal-sludge-management-lime-treatment-bentiu-south-sudan.pdf

Interlinking waste management and energy (biogas) production from waste materials is a key step in utilizing anaerobic digestion for both sanitary and value-recovery processes.

As infrastructure for anaerobic technology improves, there will be an extension and diversification of anaerobic processes to include industrial steps such as anaerobic fermentation. With Anaerobic fermentation, raw materials for secondary industrial applications are produced such as alcohols and volatile fatty acids. These chemicals can be used to produce industrial solvents and alternative fuels such as biodiesel.

Having seen the economic and environmental benefits of adopting anaerobic processes, it's evident that the advantages are far-reaching. Therefore, the following recommendations are critical for effective transition to green energy.

I. Formulation of policies and regulations that encourage investment in anaerobic technology. The policy framework should focus on prioritizing anaerobic digestion facilities as they are cheaper, compared to aerobic fecal sludge treatment facilities and financing these installations (anaerobic facilities) through provision of loans. Entrepreneurs working on biogas projects should be supported financially to motivate them to increase their efforts.

II. There is a need to develop South Sudan Biogas Program that can be funded by government, private sector donors and development partners such as Dutch Government. Such program should contain modalities as to how the biogas sector can be developed and commercialized. This program, therefore, can speed up the country's transition to clean energy production to meet the UN SDG 7.

III. There should be constructive partnership between the government and development partners like IOM for capacity building and sharing of experiences regarding biogas production. The government and private sector need to collaborate with these partners to ensure that there is sufficient awareness about the importance and safety of biogas.

IV. There is a need of strategized research that will inform policies and interventions by the government to popularize green energy. As stated earlier, there is only 5.4% of South Sudanese who have access to electricity. Intensifying research and policy interventions regarding biogas production will contribute to increased innovation and access to diversified sources of energy.

References

Agler, M. T., Wrenn, B. A., Zinder, S. H., & Angenent, L. T. (2011). Waste to bioproduct conversion with undefined mixed cultures: The carboxylate platform. Trends in Biotechnology,29(2),7078.https://doi.org/10.1016/j.tibtech.2010.11.006Leendertz, S. A. J. (2016). Testing new hypotheses regarding ebolavirus reservoirs. *Viruses*, *8*(2), 30.

Bina, O. (2013). The green economy and sustainable development: An uneasy balance? Environment and Planning C: Government and Policy, 31(6), 1023–1047. https://doi.org/10.1068/c1310j

Jha, A., & Kumar, A. (2019). Biobased technologies for the efficient extraction of biopolymers from waste biomass. Bioprocess and Biosystems Engineering, 42(12), 1893–1901. https://doi.org/10.1007/S00449-019-02199-2

Greses, S., Tomás-Pejó, E., & González-Fernández, C. (2021). Short-chain fatty acids and hydrogen production in one single anaerobic fermentation stage using carbohydrate-rich food waste. Journal of Cleaner Production, 284, 124727. https://doi.org/10.1016/J.JCLEPRO.2020.124727

Kleerebezem, R., Joosse, B., Rozendal, R., & Van Loosdrecht, M. C. M. (2015). Anaerobic digestion without biogas? Reviews in Environmental Science and Biotechnology, 14(4), 787–801. https://doi.org/10.1007/s11157-015-9374-6

Kumar, A., & Samadder, S. R. (2020). Performance evaluation of anaerobic digestion technology for energy recovery from organic fraction of municipal solid waste: A review. https://doi.org/10.1016/j.energy.2020.117253

Holtzapple, M. T., Wu, H., Weimer, P. J., Dalke, R., Granda, C. B., Mai, J., & Urgun-Demirtas, M. (2022). Microbial communities for valorizing biomass using the carboxylate platform to produce volatile fatty acids: A review. Bioresource Technology, 344. https://doi.org/10.1016/J.BIORTECH.2021.126253

Tiitmamer, N.: & Anai, J. G. (2018). Transitioning to Renewable Energy: An Analysis of Energy Situation in Juba, South Sudan. *Special Report*. Sudd Institute, Juba, South Sudan.

Rahman M.M., Hasan M.F., Saat A., Wahid M.A. (2017). Economics of biogas plants and solar home systems: For household energy applications. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 33, Issue 1 (2017) 14-26.

H. Hahn.(2015). Economic and ecological evaluation of biogas plant configurations for a demand oriented biogas supply for flexible power generation.

N. Phuangpornpitak and S. Tia (2013). Opportunities and challenges of integrating renewable energy in smart grid system. *Energy Procedia*, vol. 34, pp. 282–290.

About Sudd Institute

The Sudd Institute is an independent research organization that conducts and facilitates policy relevant research and training to inform public policy and practice, to create opportunities for discussion and debate, and to improve analytical capacity in South Sudan. The Sudd Institute's intention is to significantly improve the quality, impact, and accountability of local, national, and international policy- and decision-making in South Sudan to promote a more peaceful, just, and prosperous society.

Authors' Biography

Nhial Deng Nhial KAMOT is a research associate at the Sudd Institute, with a broad research interest in resources recovery from waste, drinking water and wastewater treatment, solid waste management, and climate change resilience in South Sudan. At the same time, he is a Lecturer at the University of Juba in the School of Natural Resources and Environmental Studies, department of Environmental Science. He holds a bachelor's degree in environmental engineering from Akdeniz University and an International Master of Environmental Technology and Engineering from IHE Delft Institute of Water Education in partnership with Ghent University and University of Chemistry and Technology, Prague. He also holds another Master in Innovation and Entrepreneurship from Vlerick Business School.