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CASE STUDY

Africa's Energy Availability-Deficiency Paradox: Lessons from Small-scale Biogas Technology and Policy Implications

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Abstract

The energy crisis associated with energy poverty in Africa continues to keep millions of men, women and children in absolute poverty due to inadequate access to clean energy. Despite its widely recognised importance for sustainable development, theoretical and policy discourses have largely remained dormant with respect to the role that the paradox of energy deficiency plays in the underdevelopment of Africa. This study illustrates how the exploitation of energy potential can be tailored to exert a positive impact on household livelihoods and sustainable development in Africa. Specifically, this study was aimed at determining the impact of biogas technology on the livelihood of beneficiaries and estimating the environmental benefits of biogas technology in terms of global warming potential in order to provide policy recommendations. The results show that the beneficiaries' livelihood assets, including the human, physical, financial and social capital, were positively impacted by the use of biogas technology. The dominant impact of biogas technology was financial, as the beneficiaries witnessed a significant increase in their household incomes. This was possible through the reduction of the expenditure on fuelwood and the sale of digestate. The environmental benefits of disseminating biogas technology as a cleaner energy source were significant, providing evidence that mobilising the biogas potential in Africa would lead to significant decarbonisation of household energy supply. This shows that integrating the livelihood enhancement components in energy interventions amid the enormous unexploited energy potential would contribute to the sustainable transformation of the African continent. In resonance with Agenda 2030, we conclude by contributing to repositioning energy availability, affordability, and reliability as critical components of an energy revolution for sustainable development in Africa.

Keywords Energy · Poverty · Biogas · Policy · Sustainable development · Africa

1 Introduction

The importance of access to energy becomes more evident when one recognises that it is crucial to achieving many, if not all the other goals outlined in Agenda 2030 (Morrow, 2018). As ascribed to the United Nations Environment Programme (UNEP, 2017), the

Extended author information available on the last page of the article primary function of energy systems is to contribute to a better quality of life. Access to modern energy unlocks improved healthcare, education, economic opportunities, and even prolongs life. It is a significant constraint to social and economic development for those with limited or no access. Energy is, therefore, essential for human existence and sustainable development. Despite the important role played by functional energy systems, energy resource-rich (high untapped potential) Africa will not achieve SDG7 in 2030 (AfricanUnion, 2015). The African Union (2063) rather plans to achieve the latter goal in 2063, that is, 33 years offset from the developed world.

The paradox of Africa's renewable energy potential lies in the fact that, with the immense potential of renewable energy resources, utilisation is still very low and insufficient to power the continent (Ogunniyi, (2019)). A key challenge for Africa to reduce its current energy deficiency lies in its weak capacity to harness, exploit, and use its rich stock of energy resources (UNEP, 2017). Although drivers and barriers to electrification are country-specific, they are often strongly related to factors such as the levels of participation of different actors (including the private sector), political ambitions and priorities, availability of appropriate human capital and funding dependency, low rural markets, the level to which electrical equipment and spare parts are available, price distortions, adaptation failure, and socio-political and environmental instability (Bonan et al., 2017). These barriers are surmountable, in as much as they are not natural, but are more likely to emanate from deficiencies in human capacity, egoism, and other society-based processes.

Currently, the preferred approach by governments to addressing energy access in Africa has been through large-scale electricity grid rollout programmes. For people living in rural areas, often without a nearby grid, this approach is impractical and unsustainable in the long term. The future energy access of these areas depends on the promotion of small-scale or decentralised energy systems, including household biogas plants. Most past and current scholarships on energy in Africa have been focused on.

Developing renewable energy sources (Hafner et al., 2018; Ouedraogo, (2019)) to meet the growing energy demand (Mukoro et al., (2022); Sanoh et al., (2014)), climate change mitigation (Abdelrazik et al., (2022); Africa Progress Panel, (2015)) and the utmost goal of achieving African development goals (IEA, 2022). As a complement to other studies, this study mainly aims to provide an energy supply approach that focuses on creating immediate positive impacts on the livelihood of households and sustainable development. Beginning with a review of the impact of energy deficiency on sustainable development in Africa, this study specifically aims to (i) determine the impact of biogas technology on the livelihood of users, and (ii) estimate the environmental benefits of biogas technology as a cleaner alternative household energy. Evidence was gathered from an international intervention to promote biogas technology in Cameroon. Based on the findings, policy recommendations were proposed. These will be useful to energy policymakers in Africa striving to reduce energy poverty and deficiency amid high energy potentials.

2 Overview of the impact of energy deficiency on the sustainable development of Africa

Non-renewable energy sources have been responsible for high greenhouse gas (GHG) emissions and exposing both humans and nature to high levels of different forms of risks (UNEP, 2017). Current policies have been focused on the transition to low-carbon or renewable energy sources. Despite the huge renewable energy potential to meet the development needs of the African population, access to energy remains the lowest, compared to other parts of the world. The general focus of energy access in developed countries (at least within the framework of Agenda 2030), is rooted in the philosophies of achieving global access, security, justice and human dignity (Melber, 2017). For developing countries, the focus has been in part on income generation, reduction of oil dependency and meeting the rising needs of economic growth (Newell & Mulvaney, 2013). Generally, renewable energy is instrumental to the achievement of the United Nations' Sustainable Development Goals (SDGs).

In 2018, the African Development Bank (ADB) reported that Africa has a solar potential of 10 TW, 350 GW of hydro, 110 GW of wind, and 15 GW of geothermal energy. Moreso, Africa has the potential to reach a renewable energy capacity of 310 GW by 2030. According to the International Energy Agency (IEA, 2022), 600 million people, or 43% of the total population, lack access to electricity, most of them in sub-Saharan Africa (SSA), while 970 million Africans lack access to clean cooking. This energy deficiency has a significant negative impact on the development of the continent.

One of the impacts of energy deficiency in Africa is the high level of poverty prevailing across Sub-Saharan Africa. This is not only reflective of low energy consumption patterns but has also been partially conceptualised as the result of an extremely low energy supply, which, when available, is persistently expensive and unreliable (Blimpo & Cosgrove-Davies, 201; Kolawole et al., 2017). SSA, which accounts for around 13% of the global population, consumes only 4% of the total global energy (Kolawole et al., 2017). According to the ADB, per capita energy consumption in SSA (excluding South Africa) is 180 kWh, compared to 13,000 kWh per capita in Europe and the United States. So, it is not a mere coincidence that Africa displays the highest proportion, i.e. 490 million people in Africa living in extreme poverty, or 36% of the total population living below the poverty line (Human, 2021). Power deficiency is a key contributor to catalysing the establishment and perpetuation of poverty traps (Quitzow et al., 2016; [UNEP, 2017). Farm power in African agriculture still heavily relies on human muscle power and the use of hand tools (Ouedraogo, 2017). In 2021, nearly 60% of health centres in SSA still did not have access to electricity. This implies that refrigerators also have unstable electricity, compromising not only the long and safe storage of food but also medicines and vaccines. Half of the vaccines in Africa are ruined due to lack of refrigeration (UNEP, 2017). Exceptions are only found in North African countries and South Africa, with significantly higher levels of electrification and overall energy consumption (Kolawole et al., 2017; [Quitzow et al., 2016). This retrospect demonstrates that energy deficiency is largely responsible (at least partially) for the very slow pace of development in SSA.

The distribution of modern energy in Africa has also been constrained by very high prices, erratic, insufficient and highly unreliable supply, thereby scaring private investors and discouraging foreign direct investments, especially in the SSA region (Quitzow et al., 2016). This also has a direct negative impact on the economic and social development of the population. The African energy scenario under study gives a feeling of desperation. The good news is that the challenge of African energy poverty is surmountable, and the benefits of success are immense. The greatest window of opportunity lies in harnessing and appropriating its renewable energy options. The renewable energy potential can be exploited in the short run by importing technical know-how from more developed regions and sustained in the long run through capacity building and adapting the technologies to the African context.

Renewable energy has the potential to offer multiple benefits and immense opportunities to Africa. Firstly, they are domestically convenient and readily supported by the international community since they promote processes and efforts towards reducing global GHG effects. According to [UNEP, 2017 If well harnessed, renewable energy sources will provide more than 40% of all energy generated in Africa by 2040 (Quitzow et al., 2016). Net energy importers can potentially reduce energy imports by exploiting renewable energy sources, whereas energy-exporting countries can increase revenues from energy exports if a substantial amount of locally consumed energy can be generated through renewable sources. Secondly, Africa's existing energy resources are more than sufficient to meet its overall needs, although they are currently unevenly distributed and under-developed (UNEP, 2017). Thirdly, Africa is home to major energy-producing countries, such as Nigeria, South Africa, and Angola, and emerging producers such as Mozambique and Tanzania. South Africa is the world's seventh-largest coal producer and accounts for 94% of Africa's coal production (Oyinola et al., 2020; [UNEP, 2017). Such experience can help the continent to reap increased economic benefits and enhance broad-based economic growth in Africa. Fourthly, the energy sector and the renewable energy subsector in particular, largely benefit from favourable policies (UNEP, 2017). The African Union's energy policy, for instance, supports vast, efficient, reliable and cost-effective energy sources within the continent (Kazimierczuk, 2019).

Africa can achieve a cost-effective renewable energy revolution for all households, businesses, industries and institutions by 2063. This initiative benefits from the African Development Bank's New Deal on Energy for Africa. This deal aspires to achieve the rather ambitious goal of universal access to electricity in Africa by 2025, using the latest off-grid and technology solutions (UNEP, 2017). Such a favourable policy environment can foster the energy revolution urgently needed to curb poverty across Africa. The international community is also willing to support the development and/or expansion of environmentally friendly energy technologies within the framework of Agenda 2030 (Melber, 2017). This, in addition to various bilateral agreements with individual countries, provides a huge opportunity for energy revolution on the African continent. Surmounting energy poverty in Africa is, therefore, possible. The Heifer Project International (HPI) is one of the organisations working to end hunger and poverty in a sustainable way by supporting and investing alongside local farmers and their communities. As part of its activities, it implements small-scale energy projects. This study was inspired by a two-year (from 2012 to 2013) biogas project implemented by the HPI in Cameroon.

3 Access to energy and poverty reduction in Cameroon

In 2015 the total electricity production for Cameroon was estimated at 628 ktoe with about 75% of it produced from hydroelectric sources. Also, in 2015 the electricity consumption was estimated at 526 ktoe, about 16% lower than production, with the industry consuming over 40% of the energy (UNEP, 2017). Hydropower is likely the most dominant form of energy for over 25 million inhabitants in Cameroon. Its technically exploitable hydropower resources currently stand at 115,000 GWh per year, making her the fourth largest potential producer of hydroelectricity in Africa. The installed capacity in 2020 is 792 MW, generating 5340 GWh (IHA, 2020). The key hydroelectric power plants of Cameroon are Lagdo (72 MW), Edea (263 MW) and Songloulou (388 MW) (UNEP, 2017), and Lom Pangar (30 MW). Hydroelectricity in Cameroon represents over 50% of the total available electricity.

Deforestation has become a disturbing issue in Cameroon, increasing at the rate of 220,000 ha per year from 1990 to 2015, not up to 2% of trees replanted each year. This probably provides evidence of a low level of commitment to promoting sustainable forest exploitation by companies involved in this sector in Cameroon (Oginni & Omojowo, 2016). Biomass energy sources continue to be the primary option for heating and lighting for most of the poor living in agrarian areas in the country (Mboumboue & Njomo, 2018).

Despite the availability and high potential for exploitation, solar energy, an important renewable energy source (RES); contributes only 0.01% of the installed electricity generation capacity in Cameroon (Kidmo et al., 2021). Solar irradiation in Cameroon varies between 4.00 kWh/m^2 d in Buea (South West Region) and 5.99 kWh/m^2 d in Maroua and Mora (Far North Region) (Kidmo et al., 2021). Despite the great potential for renewable energy, exploitation remains very weak. The wind energy sector is not well-known, and the country has no previous experience in wind power generation (Kidmo et al., 2021). Although access to power in Cameroon has steadily improved from 29% in 1991 to 62.66% in 2018 (WorldBank, 2021), there is still a big rural–urban divide. In 2018, the urban–rural access to electricity was 93% and 23%, respectively (IEA et al., 2020).

Perhaps the potential for increasing access to electricity in rural areas in Cameroon is at least theoretically favoured by the existing policy framework and institutions. Policies seek to attract investment and strengthen the national energy sector. This is thought to be possible through the exploitation of renewable energy potentials including, especially hydroelectricity. The Ministry of Energy of Cameroon (MINEE) is the main public stakeholder promoting energy development initiatives. It defines and implements the government's energy policy. The *Agence de* Régulation du Secteur de l'Electricité (ARSEL) is the energy regulatory organ in Cameroon. Nevertheless, other actors are expected, especially in the renewable energy sector in rural areas. Civil society organisations also play a major role in promoting access to clean energy in Cameroon. It is in this light that HPI opted to increase the adoption of biogas technology in rural areas of Cameroon. This would also enable the reduction of poverty in the region. Therefore, we examine to what extent this project was able to achieve this ambitious objective among beneficiaries.

4 Materials and methods

4.1 Background information of the Cameroon case study

In the advent of the HPI in Cameroon, it focused on six out of the ten regions of the country (including the North West Regions). The project, in general, lasted for over 40 years, implementing grassroot integrated smallholder livestock and agricultural projects. The smallholder dairy development project stimulated the establishment of several zero-grazing dairy farms among rural farms in the North West Region creating a great opportunity for biogas production for domestic consumption. Biogas production was believed to reduce the anthropogenic pressure on forest resources predominantly used as a source of energy for rural farmers and improve the economy and welfare of these households and their communities (HPI, 2015). To exploit the biogas potential, HPI initiated the biogas technology intervention in 2012, and it lasted till December 2013. This intervention would not only provide household energy but also improve waste management at the farms and provide organic fertiliser for crop production.

The North West Region is part of the Western Highlands of Cameroon. The Western Highlands is one of the major ecological zones in Cameroon (Innocent et al., 2016). Apart from playing host to the largest numbers of mountainous plants and animals, it consists of forest and grassland (Toh et al., 2018). Many predominantly rural households in the highlands rely on fuelwood for energy supply (Kimengsi et al., 2020). Fuelwood consumption in rural areas of these highlands is currently estimated at approximately 71,027 tons per year (Eba'a et al., 2016). The need for alternative energy is, therefore, obvious, considering that the need for energy has increased the level of deforestation in the region (UNEP, 2017). With this in mind, HPI initiated as part of a project to promote the production and consumption of biogas as an alternative to fuelwood in selected households in the North West Region of Cameroon. The project's objective was to reduce energy deficiency and improve the livelihoods of beneficiaries through the promotion of domestic biogas technology. The pilot project directly targeted 800 resource-limited dairy cattle farming rural households in seven communities in North West Region of Cameroon. The target beneficiaries were dairy farmers who were all practising the zero-grazing system.

4.2 Data collection

Data collection for this study began in 2015, as some of the impacts of the project could already be measured on the beneficiaries of the biogas project. The beneficiaries were the only target group because they were the first adopters of biogas technology in the region. So, there was no control group. Both qualitative and quantitative data were collected during on-site visits and face-to-face meetings with respondents. The variables are presented in Table 1. Data were collected through interview of beneficiaries, focus group discussions (FGD) and observations. The interview of each beneficiary lasted for 30 min. During each interview, data were collected with a pen and paper. Mostly quantitative data were recorded during this interview. One FGD each was organised for Santa Mbei and Santa Njong while another was organised for Bamendankwe and Akum due to their proximity. A FGD was held for each of the other locations, making a total of five FGDs for this study. This was necessary to discuss and further understand the common problems with the biogas technology, the contribution of biogas adoption to household poverty reduction. Observation guides were used to understand how biogas energy is used in households. The daily biogas consumption in households was reported in litres (by the respondents) and the corresponding volume in cubic metres was calculated. Field research was undertaken by a gender-sensitive team of six experienced experts. The impact assessment was captured mainly through a 'before' and 'after' comparison of variables of interest in the questionnaire (Balgah et al., (2012); [rawford et al., (2008); Khandler et al.,(2010)).

4.3 Sampling techniques

The research made use of purposive, stratified and random sampling techniques. This study purposely targeted biogas users who benefited from the biogas projects. The first level of stratification allowed for identification of beneficiary communities (sampling units) to be included in the survey. This method led to the identification of all the 45 biogas plants in the region, being part of the 1000 biogas plants that were expected to be constructed by HPI project in Cameroon. This was the second level of stratification. The third level was gender-based, including male and female beneficiaries. In each gender stratum, sampling units were then randomly drawn. This led to the identification of 45 respondents (27 males and 18 females)

Table 1 Variables and sampling units

Quantitative	Qualitative	Sampling unit (community)	Number of respondents
Fuelwood consumption (kg)	Social relationship at household	Akum	4
Cost of fuelwood (FCFA)	Health of household members	Awing	6
Household income (FCFA)	Level of satisfaction with biogas technology use	Bamendankwe	9
Age of household head (years)	Level of satisfaction with biogas technology management	Kedjom Ketinguh	4
Gender of household head (Number)	Food consumption times	Santa Mbei	6
Household size (Number)	Problems with biogas technology	Santa Njong	9
Number of dairy cattle heads (Number)	–	Vekovi	7
Size of biogas plant (m^3)	–	–	–
Biogas consumption (m^3/day)	–	–	–
Total			45

were retained for this study as shown in Table 1. The number of females was lower since fewer women originally benefitted from the project. In addition, the higher number of males resulted from the fact that most households in the study areas were headed by males.

This study was limited to a small number of small-scale biogas plants which represents a very small share of energy supply in Cameroon and Africa. Notwithstanding these biogas plants were useful to justify how energy deficiency persist in households despite the available potential. Another limitation was the Cameroon case study which cannot fully and independently justify the general situation in Africa. It rather provides insights into the energy paradox in Africa and provides sufficient data for the analysis in this study. Despite the comprehensive approach focusing on household biogas technology in Cameroon, an assessment including the situation of other countries in the continent would provide further evidence on the wider impact of mobilising the biogas energy potential on the reduction of energy deficiency and poverty in Africa.

4.4 Data analysis

This study applies the sustainable livelihoods framework (SLF) to demonstrate how increased access to energy from small-scale biogas technology can impact the livelihoods of beneficiaries. The livelihoods framework is used to unravel the complexity of people's livelihoods, especially the livelihoods of poor people, whether they be rural or urban (Soas, 2019). It seeks to understand the various aspects of a person's livelihood; the strategies and objectives pursued, and associated opportunities and constraints. Quantitative data were recorded in the SPSS (Statistical Package for the Social Sciences) software version 20.0 and the descriptive data analysis was performed for the means and standard deviations. Based on the livelihood portfolio (that is, human, physical and financial and social assets) of the SLF (Scoones, 1998, DFID, (1999);), the livelihood situation of targeted households pre- and post-HPI project was compared to identify any significant differences. Qualitative data were used to triangulate and interpret the results. Apart from assessing the livelihood situation of the households due to the use of biogas energy, the environmental benefits were assessed to reveal the global warming potential (GWP) or decarbonisation potential of adopting biogas technology. The estimation of the the of the GHG emissions from the combustion of biogas in kgCO_2e using Eq. 1. In the calculations, the energy (calorific) value of biogas was considered to be approximately 20 MJm^{-3} (Kizilaslan & Kizilaslan, 2007). The GHG emission factors of biogas were 54,600 $mgCO_2MJ^{-1}$; 5 $mgCH_4\ MJ^{-1}$ and 0.1 $mgNO_2MJ^{-1}$ (Mengistu et al., 2016). All the households burnt the biogas produced in biogas stoves and used it for cooking.

$$\begin{aligned} E &= \sum_{i=1}^{n} (C_i \text{ x } EF_{CO_2} \times GWP_{CO_2} + C_i \times EF_{CH_4} \times GWP_{CO_2} + C_i \times EF_{N_2O} \times GWP_{N_2O}) \\ &= \sum_{i=1}^{n} (C_i \times (EF_{CO_2} + 25 \times EF_{CH_4} + 298 \times EF_{N_2O}) \end{aligned} \tag{1}$$

where E = GHG emissions in kg from the combustion of biogas; n = total number of sample households; C_i = amount of biogas consumed by the sample households; C_i = amount of biogas consumed by a sample household 'i'; EF_{CO_2} = CO_2 emission factors for biogas; EF_{CH_4} = CH_4 emission factor for biogas; EF_{N_2O} = N_2O emission factor for biogas; GWP = global warming potential for the GHG indicated. Equation 2 was used to estimate

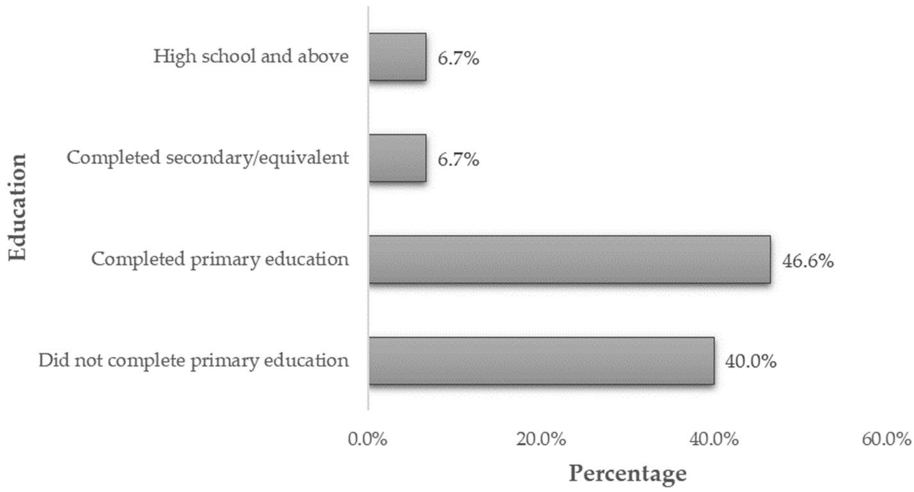

Fig. 1 Level of education of biogas users

the annual GHG emissions that can be reduced due to the use of biogas plants in the rural households (Mengistu et al., 2016).

$$E_{CO_2e} = YC \times P_{CH_4} \times GWP_{CH_4} \times R \tag{2}$$

where E_{CO_2e} = average annual GHG emission of methane from the biogas plants in $kgCO_2e$; YC = annual average biogas generation from the biogas plants in kg, given that the average daily biogas production is $5.6m^3$ and $1m^3$ of biogas = 0.7 kg; P_{CH_4} = volume fraction of the methane in biogas which was 56%; GW P_{CH_4} = GWP of methane in CO_2e, which is 25; R = average fugitive emissions of methane which is about 10%.

5 Results and discussion

5.1 Socio-economic description of the sample population

Male beneficiaries of the HPI biogas project constituted 60% of the final sample, while 40% were females. This largely reflects the situation in Cameroon, where patriarchal systems exist and male dominance in terms of access to resources is common (Balgah, 2016). It can be seen in Figure 1 that less than 14% of the household heads completed secondary school and above. In terms of their highest level of instruction, the majority had completed primary school (over 46%, less than the national average of about 72%). The other 40% did not complete primary school. This suggests that households are generally poor in human capital. The results resonate with previous knowledge that the poor in developing countries, at least from an educational perspective (human capital) perspective, are found mainly in rural areas (Kolawole et al., 2017; [UNEP, 2017). In 2015, the youth literacy rate for Cameroon was 83.8 % (Knoema, 2023). Our results showed 40% of beneficiaries are probably illiterate since they did not complete primary school, suggesting that the project fulfilled its aim in reaching out to the poorest in the target communities.

Table 2 Average respondents' age and household size

Variable	Minimum	Maximum	Mean	Standard deviation
Age of respondent (years)	26	71	48.90	10.93
Household size (number)	2	15	7.54	2.34

Table 3 Impact of access to biogas technology on human capital

Variable	Period	Minimum	Maximum	Mean	Standard deviation	*p*-value
Daily food consumption	Before biogas energy access	2	3	2.72	0.45	0.09
	After biogas energy access	2	4	3.00	0.63	
Weekly meat/fish consumption	Before biogas energy access	1	8	3.06	2.18	0.06
	After biogas energy access	1	8	4.06	2.20	

The average household size was 8 persons. The age of the respondents and household size influenced the amount of labour and revenue available for the successful construction of biogas plants. The ages of the household heads (respondents) ranged from 26 to 71 years. The average age of the respondents was about 50 years. In Table 2 is a summary of the results.

5.2 Impact of biogas technology on livelihoods

In this section, the impacts of the biogas project are presented and discussed based on the SLF livelihood asset portfolio.

5.2.1 Human capital

The impact of the intervention on human capital were captured by comparing the variables before and after the intervention as shown in Table 3.

On average, the daily number of times meals that were consumed is approximately 3. There was no difference after adopting biogas technology. Notwithstanding, protein-rich food (meat and or fish) was consumed three times ($p=0.06$) per week as opposed to two times before the adoption of biogas technology. Both male and female beneficiaries of households had a similar situation. The results are significant at 10% level, which is noticeable since the sample is rather small. They can be interpreted so that beneficiary households enjoy increased consumption, presumably as a result of the decrease in fuelwood expenditures after the adoption of biogas technology. This is not different from the results obtained by. Balgahet al., 2018 Although the level of significance seems weak, the difference can be very important from an economic perspective (Rommel & Weltin, 2017). The analysis of qualitative data shows that households consume a variety of foods due to increased crop diversification. The diversification resulted from the use of bio-slurry (fertiliser) to grow more crops than was the case before the technology intervention. In fact, 89% of beneficiaries attested to have witnessed an increase in food types consumed since the inception of the technology. They attested to the fact that more food varieties have also increased food sales (especially of vegetables). The increased household income is used to purchase protein-rich food, especially additional fish and/or meat. Consumption of more nutritious food varieties coupled with a reduced cooking workload created more rest and leisure time for beneficiaries, especially women who are often in charge of domestic work in developing countries (Balgah, 2016). The reduction of toxic gases, such as smoke from biogas stoves, was found to reduce ocular problems and few respiratory diseases were observed for beneficiaries. This was confirmed during the focus group discussions. One of the beneficiaries clearly said the following:

> *Since we were introduced to this biogas technology, we are feeling better healthwise. The smoke and wood ash that used to enter our eyes when we were struggling with fuelwood is no more. Two group members who always had coughs told me last week that this greatly subsided without any medication. I am very sure the cough was coming from the smoke in the fuelwood kitchen. We are grateful to HPI for this wonderful gift (the biogas system)* [Female beneficiary from Vekovi, Cameroon].

This information points to the conclusion that biogas technology positively impacted the health of members of households that adopted biogas technology. This was acknowledged by 73.3% of all interviewed beneficiaries. The results are similar for both the female and male-headed beneficiary households (74.1% for females and 72.2% for males). Our results mirror those from previous research (Abadi et al., 2017; [Pizarro-Loaiza et al., 2021). Other similarities to our case study reported by the authors include a reduction in workload, especially with the purchase of fuelwood by women and time savings in cooking due to the ease of cooking with a biogas stove (as reflected in [Roubík & Mazancová, 2019).

5.2.2 Physical capital

Physical capital was evaluated on the basis of the number of cattle and farm size on which fertiliser from biogas was used to produce crops and improve pasture. The average number of dairy cattle significantly increased after the adoption of biogas technology by households (from 1 to 3.14 ± 4.74, $p = 0.003$). The benefits of utilising biogas seem to have motivated farmers to boost their stock of diary animals, as this ensures a regular and stable supply of manure to feed into the bio-digester. However, information from focus group discussions showed that some farmers obtained new stock to replace the former ones. In such situations, the biogas project only provided an additional benefit. The results of Table 4 show that the average area of agricultural land cultivated by the households was proportionately reduced to the adoption and use of the biogas digester (1.59 ± 1.55 before and 1.22 ± 1.04 with biogas, respectively, $p = 0.05$). This relates to studies conducted by Shalloet al., (2020) and. Lwizaet al., (2017) On the other hand, the area on which pasture for the dairy is now developed has increased (0.65 ± 0.48 before and 0.71 ± 0.57 after, respectively), even if the increase was not statistically significant. This is expected, as more land was needed for feeding cattle than for agricultural production. With land as a limited resource, it was only logical that agricultural land is transformed into pasture lands.

Information from FGDs and KII suggests that many farm households no longer cultivate on distant farms because productivity increased significantly on home gardens and other

Table 4 Impact of biogas technology adoption on physical capital of beneficiaries

Variable	Period	Min	Max	Mean	Standard deviation	*p*-value
Number of cattle owned by household	Before biogas energy access	2	2	2	0.0	0.00
	After biogas energy access	1	5	3.1	4.7	
Land for agricultural production	Before biogas energy access	0.5	6.0	1.6	1.6	0.05
	After biogas energy access	0.5	4.0	1.2	1.0	
Land for pasture development	Before biogas energy access	0.3	1.5	0.7	0.5	0.52
	After biogas energy access	0.4	2.5	0.7	0.6	

plots closer to the house since they started applying slurry left obtained as a by-product of the biogas production process. They no longer saw the need to continue travelling long distances for cropping because the yield from the nearby farm plots on which slurry is used became very high. As reported by a beneficiary:

> *Since we joined this program, we have been generating more manure by ourselves. We then use it to fertilise our farms around the compound. We are also growing new garden crops like huckleberry and tomatoes, which we were buying from the market. Last year, I harvested 2 bags [equivalent to 100 kg] of huckleberry and 6 baskets of tomatoes [approximately 150 kg]. We ate half of our harvest and sold the rest. The additional money was used to buy books and pay school fees for our children who attended school regularly last year. Besides, we no longer need to beg and cultivate farms far off from the village.* [Male beneficiary in Bamendankwe, Cameroon].

Furthermore, the fact that slurry was available for fertilisation of pasture, motivated them to increase their pasture lands. However, a limitation to this is the number of cattle owned, as women, in particular, cannot sustain a large number due to limited access to or control of the land from which pasture is developed (Balgah, 2016). According to, Fon, 2011 about 75.7% of women in Cameroon do not have control over arable land. These women persistently have less access to productive resources than men (Njikam et al., 2021). This probably explains why the land under cultivation with bio-fertiliser is significantly lower for women than men (0.5 ha and 0.9 ha, respectively, $p = 0.00$). However, a female beneficiary in Njong reported that: '*It is possible for other women and me today to acquire land for bio-digester construction through purchase and family*'.Fon, 2011 further emphasises that rural women in Cameroon can access arable land through other sources, in order of importance, family, soliciting, gift, renting and communal.

5.2.3 Financial capital

Reasonably, the dominant impact of adopting the biogas technology can be seen in the increase of household income and expenditure, as shown in Table 5. Quantitative and qualitative data reveal that farmers who adopted biogas plants witnessed a tremendous upsurge in their financial assets in terms of the reduction in the expenditures on other energy sources like fuelwood and charcoal as well on chemical fertilisers.

During a year, farmers now spend FCFA 71,120 (≈US$ 118) lower on fuelwood and FCFA 20,610 (≈US$ 34) less on inorganic fertilisers. This showed that biogas technology

Table 5 Financial impacts of adopting biogas technology

Variable	Period	Min	Max	Mean	Std. Dev	*P*-value
Quantity of fuelwood used yearly (in trucks)	Before energy access	30.4	152.1	65.5	26.9	0.005
	After energy access	6.1	91.3	29.7	18.3	
Annual expenditures on fuelwood/FCFA	Before energy access	0.0	307,000	143,040	115,550	40.004
	After energy access	0.0	307,000	71,120	73,770	
Annual expenditures on inorganic fertilisers/FCFA	Before energy access	0.0	181,000	50,550	32,390	40.001
	After energy access	0.0	162,100	29,990	30,110	
Revenue from sales/FCFA	Before energy access	0.0	203, 010	32,522	50,601	40.035
	After energy access	0.0	661,000	87,300	135,150	

1 US $ = FCFA 600 (adjusted to the nearest FCFA)

can replace fuelwood used for cooking. This is also evident that bio-fertiliser can replace inorganic fertilisers in crop fields. This is best understood within the backdrop of the increased number of livestock stimulated by technology adoption. The increased crop production and productivity due to bio-slurry application on farms provided households with excess food for the market, within the subsistence-based agricultural systems dominant in rural areas of Cameroon. This resulted in an average annual increase of FCFA 54,680 (≈US$ 91) from sales of food crops per household and year. The estimation of the income from the sale of crops has been done only for the two main crops (beans and maise) most cultivated in the region. A calculation of the net reduction on fuelwood and chemical fertiliser for one year and the net income earned from increased crop sales gives a total of FCFA 146,310 (≈US$ 244) per given household per annum. This justifies a significant increase in household income of 73% concerning previous annual household incomes before the technology adoption. This increase in financial capital also led to an estimated increase in annual savings of FCFA 75,600 (≈US$ 126). Adopting biogas has vested significant economic benefits for adopters. Therefore, biogas technology adoption can be considered an important means of boosting the incomes of farmers in developing, countries, particularly in rural areas. This can also help in lifting them out of poverty.[1] Similar findings have been reported by (Mukumbaet al., 2016) in South Africa; and Ofet al., (2019) in Rwanda. Our results and previous findings, therefore, lead us to conclude that adopting small-scale Biogas technology can bring economic benefits to beneficiaries.

5.2.4 Social capital

The results of the FGD revealed that, on average, almost 90%of all beneficiaries in each community were members of a social group from which information and experience is shared. In addition, they benefited through the sharing of skills and knowledge by members who were more familiar with biogas technology. Consequently, they got consultation and expert services from fellow members in the management of their biogas plants for free or at prices lower than prevailing market rates.

Another interesting feedback from focus group discussions was the participation of male children in cooking in the studied households as they enjoyed doing so with biogas, than was the case with fuelwood hitherto fore. This ensures the sharing of the cooking burden with male members of the family as well as a shift in family time use. The workload associated with cooking was highly reduced for the women and girls in these households, who spent more time studying. Over 50% of all households reported improved performance of children (especially the girls) in school examinations than before the technology. Households socialised more after the intervention. This is evident in that all members of the households declared that they spent more time together. Due to the adoption of biogas technology, families spend more time together in the evening around the biogas stove, even during electricity failures that are very common in the studied communities. These additional benefits identified in this study add to the other benefits identified of biogas

[1] This statement is more indicative than conclusive, considering that the non-cash economy and the household income before the project intervention were not captured during the research. It however plausible, as subsistence farmers often produce for consumption and only sell surpluses at the marketplace. It is based on this assumption that we contend that adopting biogas technology can potentially break the vicious cycle of poverty for some beneficiary households.

technology to rural communities (Ferroukhi et al., 2016) in improving the livelihoods of households and reducing rural household energy deficiency. As a beneficiary explains:

> *When HPI first arrived in our community, we did not have this type of group that could allow us to learn things that could help us improve our lives. Today, we can understand how to make and use biogas. More organisations are now working with our [new] groups, giving us financial support for our other activities (such as farming). This additional support is helping us to send our children to school. We are attracting more respect from other community members now. We owe all of this to HPI, who encouraged us to join groups during the introductory phase of the biogas project [Male beneficiary from Santa, Cameroon].*

The HPI intervention on biogas technology in this study demonstrates that energy supply in rural Africa is possible if the physical, human, social and financial capitals are applied to mobilise the available energy potential. The dynamics of these capitals is still unclear to many decision makers in the continent as it varies from one geographical location to the other. Therefore, there is need to understand these specific dynamics in order to improve the sustainability of such interventions. In addition, systems studies focused mainly on the resource potential/mobilisation and governance are needed inform decisions and actions required to improve these interventions.

5.2.5 Environmental benefits of biogas technology

Biogas technology provides several environmental benefits including reduction of deforestation due to household fuelwood demand (Subedi et al., 2014), improvement of household sanitation (Brown, 2006), reduction of indoor pollution (Rees et al., 2019) and of GHG emissions (Tagne et al., 2021). Out of the 45 biogas plants, 35 (87.5%) were fed with cow dung, while 10 (13.5%) were fed with pig waste. This contributed to improving the sanitation in the animal barns. The biogas plants varied in size from 6 – 10m^3, with an estimated average size of 8m^3. The average daily biogas production per 8 m^3 biogas plant was 5.6 m^3/day. The average methane content of biogas was 56% of the biogas produced. On average, the fugitive emission comprised 10% of the biogas produced. From Eq. (2), the annual GHG reduction from the use of the 8 m^3 biogas was estimated to be 2866 tCO_2e per biogas plant (per household). This implies that biogas is a better alternative to fuelwood used in households of non-biogas users. From this, the use of biogas in a household could lead to the reduction of 2866 tons of fuelwood in each household in a year. Mobilising the biogas potential in Africa would lead to significant decarbonisation of energy supply.

6 Conclusion and policy recommendations

6.1 Conclusion

This study has demonstrated that the energy deficiency amid huge renewable energy potential is detrimental to the sustainable development of Africa. Based on the analysis of the asset portfolio of the Sustainable Livelihood Framework and zooming into the role of small-scale biogas technology, we observed that adopting biogas technology created significant impacts on the different forms of livelihood capital assets. The strongest impacts were observed on the financial capital front. Considering biogas as an environmentally friendly energy source, an $8m^3$ sized biogas plant could contribute to the mitigation of up to 2866 tCO_2e per year.

With the available unexploited energy potential and a generally supportive energy policy and institutional frameworks, we contend that an African energy revolution is very possible. This, however demands the engagement of the international community and all local stakeholders, to commit towards enhancing a just and sustainable clean energy transition as engrained in the Agenda 2030. This is visible in our Cameroon case study, where the energy initiative of an international non-governmental organisation (Heifer Project International), was able to improve the livelihoods of rural beneficiaries as a stepping stone to sustainable energy supply and development.

6.2 Policy recommendations

Future policies to revolutionise energy access in Africa should be largely contingent on renewable energy to contribute to long-term development in Africa. Renewable energy sources (including biogas) should be made available, affordable and reliable for all, as clearly spelt out in sustainable development goal 7 of Agenda 2030. While the challenge would be to mobilise the renewable potential, designing supply projects to create an immediate positive impact on the livelihood of all persons, especially those in rural areas, is even more necessary. We contend that this can contribute to reducing poverty on the continent, partly and directly through reduced energy costs at the household level and indirectly by attracting foreign direct investments. Until this happens, energy deficiency amid abundance will continue to play a major role in hindering sustainable development in Africa.

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Author contributions RAB and CTK conceived the idea for the paper, analysed the data and identified relevant literature for the paper. RAB coordinated the field data collection. All the authors reviewed and contributed to the elaboration of the manuscript. Revisions were done by NMN, CTK, RAB and HR. Supervision was done by HR.

Data availability The data that support the findings of this study are available on request from the corresponding author,

Declarations

Conflict of interest The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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