

Full Length Research Paper

Determining the pathway for commercialization of bioenergy technologies and products among stakeholders in the bioenergy value chain in Baringo County, Kenya

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Bioenergy has emerged as a suitable alternative to fossil fuels with a potential to significantly contribute to the country's energy targets. However, the well-established fossil fuel industry presents a challenge for the development of a commercially viable bioenergy industry. Other factors such as government policies, financial constraints, lack of stakeholders' coordination, technical complexities, and market chain barriers also contribute to the stagnation of the sector. This paper analyzes these barriers, existing opportunities to overcome the barriers and proposes a pathway to commercialize bioenergy technologies. The research placed stakeholders of the bioenergy value chain as the focus of the analysis, thus complementing the existing literature, and giving it a user-centered approach. Data was collected through semi-structured interviews and interactive focus-group discussions allowing stakeholders to share their experiences and perspectives. The analysis of the barriers to bioenergy expansion helped to identify opportunities to improve policy design and implementation, and address financial constraints and technological difficulties. This study's findings are relevant for developing transition strategies to low-carbon energy futures in Kenya and other developing countries that are struggling with energy transitions.

Key words: Bioenergy, commercialization, stakeholders, sustainability, Kenya.

INTRODUCTION

Bioenergy is regarded as the next major source of renewable energy alternative to fossil fuels. It is a major driving force to climate change mitigation which will ensure sustainability of the energy industry (Chan, 2018). Studies have noted that the development of sustainable energy sources and mitigation of climate change effects depend largely on the development of the bioenergy sector at a commercial scale (Parra et al., 2023; Smith

and Porter, 2018). The bioenergy sector has the capacity to supply approximately 15% of the world's energy demand come 2050 (Fischer and Schrattenholzer, 2001; Parra et al., 2023). Bioenergy presents a form of renewable energy that is derived from organic/inorganic substances (Shane et al., 2017). The bioenergy industry is a vital component that will enable transition from fossil (Morone and Yilan, 2020) and contribute to the

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achievement of a circular economy (Fiallos-Cardenas et al., 2022; Manzanares, 2020). It presents an opportunity to reduce the amount of carbon in the atmosphere linked to human health and environmental safety concerns. The increasing population and the rising energy demand has resulted to numerous environmental and health concerns. This has also been linked to the growing food insecurity globally. The utilization and use of biomass energy is therefore seen as an effective means to greenhouse gases emissions (Namany et al., 2019). Studies have also indicated that commercial deployment of bioenergy sources could help reduce the global temperatures below the pre-industrial levels (Bauer et al., 2020; Jouvet and Perthuis, 2013), thus helping to achieve a sustainable future.

Commercialization of bioenergy technologies therefore is as vital to in order to create path for the development of clean energy and is a direct contribution to the achievement of affordable, clean and sustainable energy (Sustainable Development Goal, SDG7), climate action agenda, SDG 13, the realization of sustainable cities and communities, SGD11 and attainment of responsible consumption and production, SDG12. It is a safeguard against environmental depletion (IEA, 2021) and a means of introducing energy efficient technologies to minimize carbon gases emissions (Jonsson and Martin, 2016). Despite the urgent need for biomass energy and the positive prospects of the bioenergy industry, commercialization of bioenergy technologies and biofuel products is still faced with several hurdles. These challenges have been presented in different forms including sustainability of production capacity of the technologies (Avila-Arozca et al., 2020), production costs (Woinaroschy, 2014), among others. This study seeks to highlight the current status of bioenergy industry, existing challenges towards a sustainable industry and possible solutions to these emerging gaps in the commercialization quest.

Several studies have attributed the staggering uptake and use of biofuels to the minimal efforts put towards commercialization (Usmani et al., 2021). A study conducted by Javed et al. (2021) states that a sustainable commercialization effort of biofuel products depends majorly on the economic sustainability of the enterprise. Emphasis is also made in studies such as Nieto et al. (2021), Frattini and Chiesa (2011) as well as Eldred and McGrath (1997b). Other studies also state factors such as the legal framework conditions and the low returns that may be realized after investing so much in making the machinery attractive (Kemausuor et al., 2015). All these studies stress the importance of a good commercialization strategy especially on a new product development and sustainability of a given value chain. Uptake of a new product in a given market is primarily dependent on the product's commercial aspect which will eventually determine its market penetration and development or failure (McKinsey, 2010).

The concept of commercialization has been give

different perspectives by different researchers. Some researchers suggest that commercialization involves a sequence of scientific work that aids in a new product development and movement from laboratory into a new market (Shakeel et al., 2017). Other studies view commercialization as a process of getting the views of the product's consumers which is based on the product's performance and reliability. The objective is to ensure that the satisfaction of a customer can be sustained throughout the life of the business (Balachandra et al., 2010). Some researchers view it as a process of using a product's uniqueness and transforming it into a sustainably profitable enterprise (Adams et al., 2006), while others state that it is the last phase of the development of a product closely linked to its launch and marketing (O'Connor, 2008).

It is evident that, as much as commercialization has been studied, it is still a growing concept. It is also to be noted that the penetration of bioenergy technologies into the market does not stop at laboratory success but largely dependent on successful commercialization. Bioenergy has the potential to enable transition into a sustainable energy industry through the use of sustainable technologies. However, this potential transition will remain on paper or inside the laboratories unless there is a large-scale diffusion of these technologies. This paper is curious to investigate the possible barrier to the development and commercialization of bioenergy technologies and possible opportunities existing that could be tapped to fill the gaps in Kenya.

By looking at the challenges hindering commercialization potential of the bioenergy value chain, this study complements the work of Balan (2014), Balachandra et al. (2010), Chandel et al. (2018) and Frattini and Chiesa (2011). The study offers an opportunity to rethink on the existing policies that would help push the bioenergy sector to sustainability.

MATERIALS AND METHODS

Study area

The study was conducted in Baringo county in Northern Kenya which is a major charcoal producer in the country. The county has a population of 666,766 people sitting in an area of 11,075.3 km². Several parts of the county are classified as arid and semi-arid regions with livestock keeping as the main economic activity and charcoal production also forming a larger part of its livelihood. The county is located along latitude 0° 39' 59.99" N and longitude 36° 00' 0.00" E with a mean monthly temperature of 32.8 ± 1.6°C and an annual rainfall of 1000 to 1500 mm in the highlands and 300 to 700 mm in the lowlands. This county was selected as part of Kenya Climate Smart Agriculture Project (KCSAP)-Bioenergy value chain project site under which the research was conducted. The county was also selected as one of the main charcoal production regions in the country making it necessary to introduce bioenergy technologies in the region. The project sought to promote climate smart biotechnologies which would help reduce the use of forest wood and lessen the amount of carbon emissions while improving the

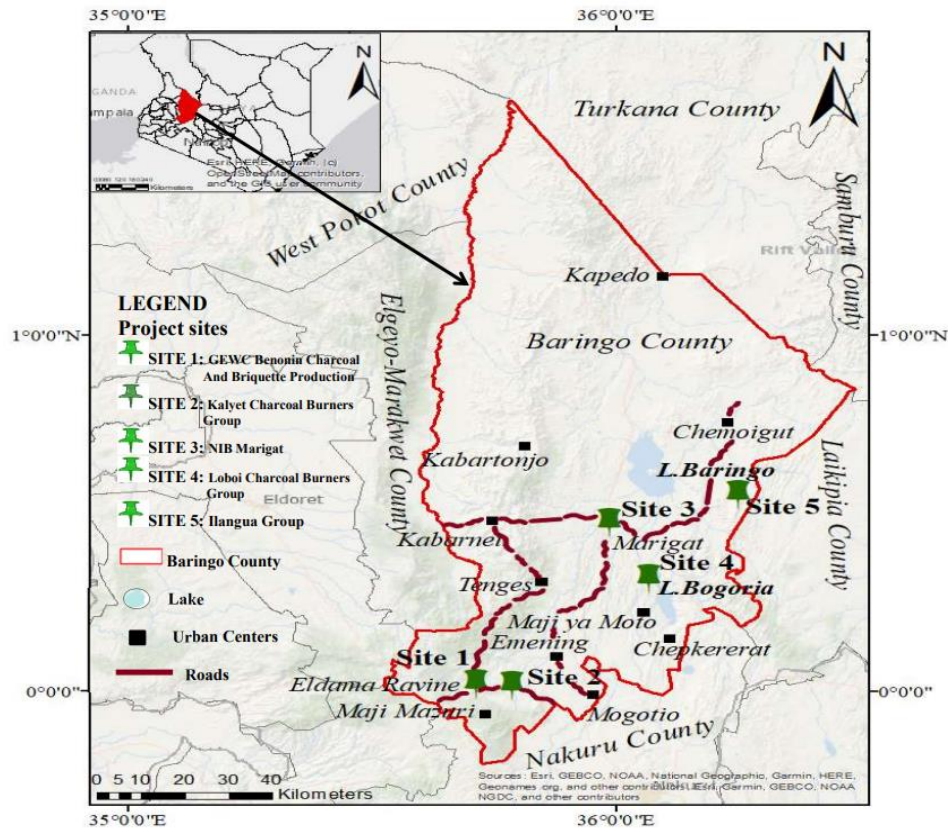


Figure 1. Map of the study area. Source: Primary Data Collection (2022).

bioenergy value chain. Five (5) sites were purposively selected, that is, GEWC Benoin Charcoal and Briquette Producers in Eldama Ravine, Kalyet Charcoal Burners Group in Mogotio, NIB Marigat group, Ilangua Group in Chemoigut and Lohoi Charcoal Burners group as shown in Figure 1. These are the charcoal and briquette producer groups directly involved in KCSAP.

Data collection

The primary research approach placed key stakeholders of the bioenergy value chain at the center of analysis. This complemented the existing literature on bioenergy giving it a user-centered approach where key stakeholders are given a chance to voice out their experiences. Two sets of stakeholder consultations were carried out engaging representatives from sectors such as policy, business, civil society and academia. A research permit was obtained from National Commission of Science, Technology and Innovation (NACOSTI) in order to carry out research in the area. Informed consent was obtained from all participants and participating in the consultations was completely voluntary. The first consultation was focus group discussion with 75 charcoal and briquette entrepreneurs, 15 from each of the 5 producer groups, randomly selected. Participants discussed the benefits of improved bioenergy technologies, barriers to commercialization of the technologies and opportunities existing for wide-scale development of bioenergy enterprises. The second consultation included 5 semi-structure interviews carried out among a variety of stakeholders

from different backgrounds like the research, environment and industry (fabricators of bioenergy technologies, Kenya Forest Research Institute, Ministry of Environment and Forestry, Kenya Forest Service, Ministry of Water, Sanitation and Irrigation). The interview included questions to identify the existing policies and strategies that support bioenergy, willingness to uptake and expectations from the community with regards to the technology, barriers and opportunities for bioenergy technology development and commercialization.

RESULTS AND DISCUSSION

Here represents the socio-economic characteristics of respondents and the results for the determination of the pathway for commercialization of bioenergy technologies and products. Majority of the respondents were male (63.75%) which would signify that the males were more proactive in new technology adoption as opposed to their female counterparts (36.25%). This would suggest a higher level of interest among males than female in the technology field. The age distribution indicated that the majority of respondents were within the younger age brackets of 18-40 years. This may imply that younger individuals are more actively engaged or interested in

Table 1. Socio-economic characteristics of respondents.

Variable	Description	Frequency	Response (%)
Gender of the respondents	Male	51	63.75
	Female	29	36.25
Age group (years)	18-30	18	22.5
	31-40	24	30
	41-50	20	25
	51-60	16	20
	>61	2	2.5
Education level of respondents	Primary education	21	26.25
	Secondary education	34	42.5
	Tertiary education	25	31.25
Occupation	Entrepreneurs	75	93.75
	Researchers	2	2.5
	Civil servants	3	3.75

bioenergy technology commercialization. A significant proportion of respondents have at least secondary education (42.5%) and tertiary education (31.25%). Higher education levels may indicate a better understanding and possibly greater involvement in technology-related activities. The study was dominated by entrepreneurs in the bioenergy value chain who were primarily selected from the entrepreneur groups in Baringo county. This dominance could also suggest that individuals directly involved in business activities would show a higher interest in technology commercialization. This aligns with the expectation that entrepreneurs are more likely to adopt and leverage new technologies for business purposes (Table 1).

Barriers and opportunities to bioenergy technologies commercialization

The discussion involves major barriers to commercialization process and possible solutions, a strengths, weaknesses, opportunities and threats (SWOT) analysis of the bioenergy value chain, and a proposed pathway for bioenergy technologies and products commercialization. The literature presents various drivers that promote the uptake of bioenergy technologies and products including (a) sustainable and renewable energy supply, (b) inclusive economic growth to reduce overdependence on fossil fuels, (c) establishment of a circular economy and contributing to building a green environment (Oh et al., 2018; Valdivia et al., 2016). However, the study identified several challenges that affect commercialization efforts of bioenergy technologies and products, including

imbalanced demand and supply of biofuels, unsteady supply of biomass used as feedstock in the production processes, lack of information flow from programmes promoters and target adopters, high capital investment and operation costs, complex technologies not meeting the needs of the adopters, insufficient public policies on biofuels, lower returns on investment and inability of the technologies to be reproduced. All these challenges were generally categorized into four themes, that is, (a) market environment barriers and opportunities, (b) technical barriers and opportunities, (c) economic barriers and opportunities and (d) policy barriers and opportunities as presented in Figure 2.

Market barriers and opportunities

A number of challenges were noted surrounding the market environment of bioenergy technologies and products. These included lack of information among stakeholder, unsteady supply of biomass, and challenges with demand for biomass energy.

Lack of information among stakeholders

Difficulties in operating most of the technologies were attributed to lack of streamlined information between the programs promoting the technologies and the adopters of the technologies. Many entrepreneurs reported that they were neither properly informed on the benefits nor trained on the functioning of most of the technologies. *“The company would just bring the machine at the learning site and offer training at the initial stages of the project, which*

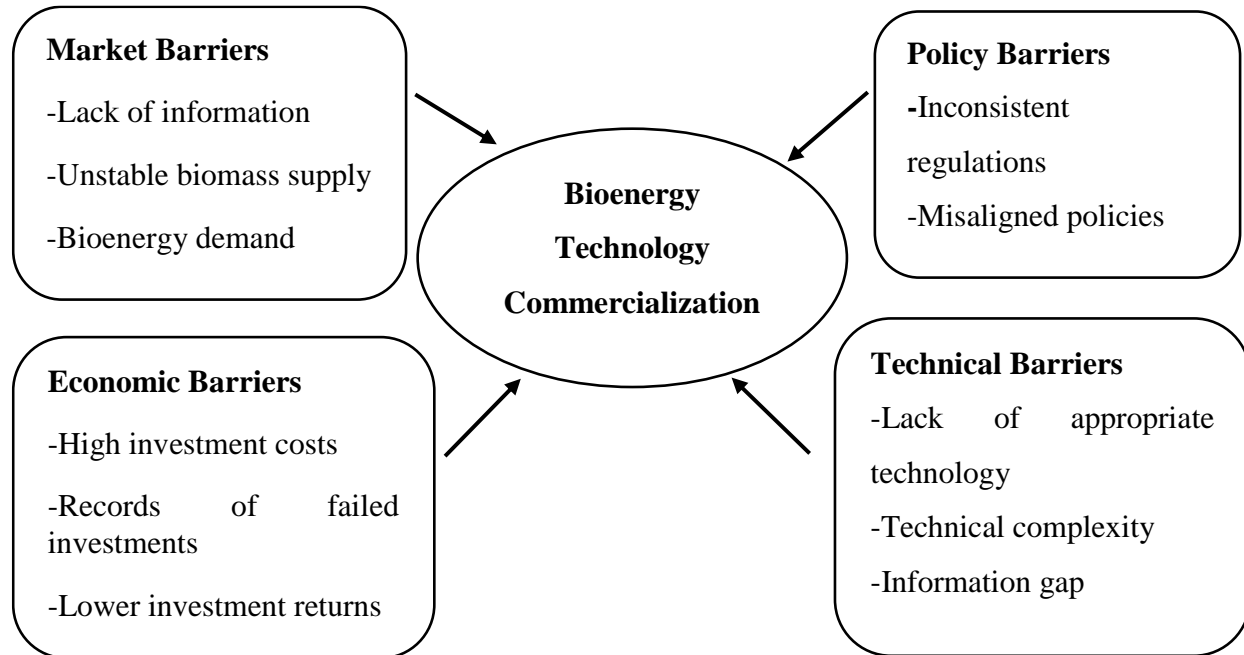


Figure 2. Major barriers affecting commercialization of bioenergy technologies. Source: Primary Data Collection (2022).

in most cases are not sufficient", said an entrepreneur. The literature points out lack of clear information as one major barrier to full commercialization of bioenergy technologies (Mwirigi et al., 2009). Information on the use of the technology should be very clear to enable adopters appreciate its benefits. Other stakeholders felt that the introduction of such initiatives in the communities did not fully take into account the opinions of the locals and identify their needs or interests before deployment. This could be the cause of poor adoption of such technologies as the locals could feel their opinions are not incorporated and thus failed full commercialization attempts.

Other stakeholders noted lack of consistent monitoring of the projects' success after deployment. Several projects, especially government supported, only conduct monitoring of the technology performance during the first few months of the project after which they stop monitoring to ascertain the success of such projects to the communities they are deployed to. They conduct patchy performance evaluations which do not encourage the adopters of the technologies. This leaves the users of the technologies trying to find solutions especially to technical problems which they may not understand well enough to solve. As a result, they end up abandoning the technology and continue with their conventional production methods. One stakeholder argued that sometimes the technologies may not even work properly in the field during demonstrations which would instill doubt among the adopters. They may question the viability of such technologies and investment feasibility.

Any doubt in operational feasibility of a technology to a user may prevent any investment attempt which would lead to such projects diminishing at the trial stage.

Stakeholders therefore suggested a transparent and reliable information flow between the promoters and the adopters of the technologies to create investment interest. Some solutions suggested by stakeholders included: community trainings and capacity building which might make the locals have interest in investing in the technologies. The government could also lead campaigns as a way of creating awareness among the communities. An entrepreneur argued that adopters of the technologies in the community can create greater influence on other members and cause wider adoption of the technology. This is particularly manifest in communities where there is communal sharing of resources like Baringo, e.g. sharing of the irrigation water from Pekerra River at the Pekerra irrigation scheme. This communal sharing creates a sense of togetherness thus the adopters have an easier lead in convincing others.

Unstable supply of biomass

A year round supply of biomass material is a critical issue when starting a bioenergy enterprise. Stakeholders reported that there is need for an agreement to be put in place between supply of the biomass material (agricultural crop residues, wood among others) and biofuel producers. The cost of managing and transporting the

feedstock from the farms to the production sites/factories is a cost that must be taken into account before engaging in biofuel production. This is because, these costs affect the overall economics of the enterprise. The literature notes that, for large scale production of biofuel, approximately 40 to 60% of the production cost is taken up by logistics, transportation, production of feedstock and feedstock processing costs (Humbird et al., 2011). The aim of any enterprise is usually to reduce cost of production and realize good returns on their investments. For cost competitiveness, the production site should be located in close proximity with the biomass material production farm so as to reduce the costs associated with logistics and transportation. Production cost will increase if the enterprise is located far from the biomass farm due to increased transport cost (Balan, 2014).

Most entrepreneurs do not take into consideration these issues especially when looking at the operational feasibility of their bioenergy enterprises. Transport cost was found to be a major factor of consideration for it cuts across all stages of production from processing of feedstock, storage and transport from the harvesting farm to the factory/production site. Entrepreneurs should also understand the type of feedstock that would ensure economic gain since different feedstock have different bulk densities. For instance, grass crops have bulk density of 50 to 100 kg dry matter m^{-3} lower than corn with a density of 721 kg dry matter m^{-3} (Chandel et al., 2018), which would in turn affect the efficiency of feedstock supply. Therefore, before engaging in a bioenergy production enterprise, it is important to ensure that the biomass supply chain is able to meet the economic aspects of the enterprise. This would empower farmers, entrepreneurs and the larger population to adopt such technologies.

Demand for biomass energy

Demand and supply are major aspects to be considered in uptake of bioenergy technologies and biofuels. Before releasing a technology/product into the market, it is important to study and ascertain the demand for that technology or product. If a technology is not able to meet the demand of the target market, then competitors including the current technologies being talked down by the industry would service the demand. Stakeholders argued that, for a technology to break into the market efficiently, it needs to create more interest to the community more than the existing and adapted technologies.

To create more interest, a stakeholder suggested, *“projects could identify better ways to exploit the markets by ensuring multiple benefits from using the technologies”*. For instance, for the case of biomass carbonization technologies, apart from getting the major output, that is, biochar, the technology is also able to produce wood

vinegar, the liquid obtained when smoke is condensed during pyrolysis of wood (Zuraida and Budijanto, 2011), which has multiple uses in pest and disease control in farm crops. The liquid has been found to contain antifungal, antioxidant and insecticidal properties (Faisal et al., 2019) which could be used to boost crop production. Wood vinegar can be used in various forms including fertilizer, plant growth hormone as well as wood preservative (Salim et al., 2021; Yahayu et al., 2017). This promotes a cyclic environment where the vinegar is used in the production of the feedstock which would eventually be used as a raw material in the carbonization process. Strengthening the market for these secondary products could be a promising opportunity for the commercialization of the technologies. These secondary products could also have a greater savings potential on the expenses of the adopters e.g. reducing expenses for purchase of chemical pesticides. Therefore, a technology that presents multiple benefits would attract more adopters who would then increase the scale of such technologies.

Policy barriers and opportunities

Several policies have been put in place by the Kenyan government to promote modern bioenergy services in which planning and development of energy regulation has been devolved by the Kenyan Constitution 2010. Biomass fuel has been recognized as a vital source of energy in the country by The National Energy Policy 2018 stating that wood fuel management is vital in order to meet the growing energy demand. The National Climate Change Action Plan (NCCAP) 2018-2022 also identifies key actions that need to be taken to ensure increased adoption of renewable energy in order to achieve a low-carbon economy (MEF, 2018). The implementation framework for energy, that includes bioenergy, has been set forth by The Energy Act, 2019 which provides regulations for licensing and management of all renewable energy sources.

With all these policies and regulations put in place however, stakeholders stated that bioenergy companies are subject to multiple fees, licenses as well as taxes especially when the company is formally registered. The regulations were also noted that they were not consistent across both formal and informal sectors. This makes the informal sectors more market competitive than the formal sector since the competition is not on a level ground. The Forest (Charcoal) Rules of 2012 gazetted in 2009 and revised in 2012, specifically regulates sustainable production, transportation and marketing of charcoal which the Kenyan Constitution 2010 mandates the county government to foresee. Entrepreneurs stated that it was difficult to get licensed for charcoal production especially as an individual since the constitution demands licensing be done to groups (Charcoal Producer Associations

(CPA)) through Kenya Forest Service (KFS) and no retailer or wholesaler is allowed to do business with unlicensed group.

At the national level, it was noted that there was misalignment of policies. This is because there are both policies governing renewable and even the coal power plants which threatens the bioenergy industry. The government may be more concerned by fueling development rather than reducing the amount of carbon emission as argued by a stakeholder. At the community level, in some cases, financial support may be given for running of the deployed technologies to a candidate who does not really care about the success or failure of the project. Basing on the criteria used by the program, for instance a candidate's past experience, the person selected might not be the best suit for the position thus resulting in project failure.

As a solution course, stakeholders argued that there could be improvement in the renewable energy policy framework. There could be more biofuel targets to motivate the private sector to invest more on bioenergy programmes. *"We could actually take the devolved government as a strength to develop the bioenergy sector"*, suggested a stakeholder. The county governments have significant policy making and budgetary powers. The government could use its powers to source funds and channel them to development of the bioenergy sector in their regions. The county government could therefore go beyond the national policies to invest in bioenergy projects towards the development of its region.

Technical barriers and opportunities

Technical complexity of bioenergy technologies is a major drawback in successful commercialization of these technologies. The research efforts in laboratories may not always be workable in the actual field where the technology is deployed (Chandel et al., 2018). There still exists a major gap between laboratory research and field operations especially at commercial levels since parameters estimated in the laboratories may not always be applicable or viable when the technology is deployed at commercial levels. An entrepreneur argued that sometimes the technology may require a lot of technological improvements in order to be fit for a commercial operation. These improvements may come with huge costs which may not be met easily by the entrepreneurs. The handling of the technology may require expertise and experience posing a challenge to entrepreneurs who might have the interest to invest but lack the expertise to operate the technology. Some entrepreneurs might not welcome the idea of incurring training costs before engaging in operations.

Processing of biomass in order to get the right feedstock may be tedious. For instance, in the case of

briquetting technologies, the raw biomass has to be processed (carbonized under low oxygen concentration) before getting the biochar as the major raw material for briquettes making. This often increases the production cost and the complexity of the production process in cases where the briquettes entrepreneur has to produce the biochar himself. A stakeholder argued that these new, technologically immature technologies can be difficult to operate since most of the faults that could have been made in the laboratories have not been removed to ensure smooth running of the machine. Thus, such technologies require that they are operated for some time to correct any technical problem that may arise before deploying them for commercial use. In order to obtain the desired product therefore, all the steps of operations especially for the automated machines should be followed as a prerequisite of the success of the bioenergy enterprise.

Economic barriers and opportunities

The study noted several barriers in the business environment that would hinder commercialization of bioenergy technologies. One major barrier was the established fossil fuel industry which has greatly spread among communities. State owned corporations like National Oil Corporation of Kenya (NOCK), dominate the industry dictating prices which the small and upcoming bioenergy companies would barely compete with. Another barrier noted by the stakeholders was lack of after-sale services such as maintenance and warranties. Bioenergy companies or institutions promoting bioenergy technologies rarely offer maintenance after the technology is deployed to the entrepreneur. This therefore forces the entrepreneurs to hire sub-standard services from uncertified technicians which consequently increase the maintenance costs. This affects the viability of such projects with regards to commercialization.

Other barriers included lack of financial support which significantly affects the implementation and development of bioenergy enterprise (Nevzorova and Kutcherov, 2019). Where an entrepreneur cannot afford the financial implications that come with implementation of bioenergy project, such project would not reach the commercialization stage (Kitheka et al., 2019). Cost deliberations are crucial in commercial activities and stakeholders argued that investors will only find a business attractive when they can afford its establishment and gain return on investment. High capital and operation costs were found to have major influence on commercialization of a bio-enterprise. Cost is an important factor to be considered in determining the overall interest in investing in any technology (Bößner et al., 2019). The cost of investing in a bioenergy technology varies depending on the season when and region where the investment will take place. The feedstock costs

especially for briquettes production varies with season and this affects the investment cost, that is, the cost of agricultural crop residues like corncobs or even forest wastes. The cost of obtaining the feedstock, storage and transportation also increases the overall investment cost (Chandel et al., 2010). Entrepreneurs will therefore invest in the business when he or she is sure of the profitability of the business.

Stakeholders suggested that entrepreneurs could come together to co-fund their investments since the investment cost of a bioenergy technology could be way above the reach of a small-scale entrepreneur. This would not just create revenues to the investors but also build a sense of ownership where they see the enterprise as a future investment which could result in a long-term commercialization plan. Co-financing has been seen to improve longevity of technology investment rather than individual financing which would be very expensive for ordinary producer (Buysman and Mol, 2013). Technology providers could also provide repair and maintenance services to the entrepreneurs in order to reduce such costs which could also come with warranties. This would greatly encourage investment in such technologies as opposed to when the entrepreneur/investor has to take care of all the costs of the technologies especially in the early stages of investment. The institutions could also invest in training communities on the operations of the technologies and training some of them as technicians which could create more job opportunities especially for the youths of the communities involved.

SWOT analysis of bioenergy enterprise

From the focus group discussions and stakeholders' interviews, a SWOT analysis of bioenergy enterprises was drawn which focused on four major parameters, that is, strengths and weaknesses which affect the enterprise from within and opportunities and threats affecting the enterprise externally. These parameters were analyzed from a business and strategic viewpoint. The results of the SWOT analysis are presented in Table 2. Several strengths and weaknesses have been noted when looking at the pathway to commercialize a bioenergy enterprise. The need to reduce carbon gas emissions in light of the changing climate, increasing demand for energy, promoting economy and creating employment is growing across the world. This growth however is seriously affected by high capital investment in the technology, high operation cost, technical complexity which does not see such projects proceed to commercialization points (Chandel and Silveira, 2017). The bioenergy industry has also offered several opportunities which if utilized can just be the breakthrough to commercialization of the technologies since climate change actions are at the top the world's sustainable development goals agenda (SDG 13-Climate

action).

Regardless of the opportunities that exist, there are those factors that threaten the development of this sector. For instance, recent failures in attempted investments in the industry still threaten any potential investor who might have interest of getting into the industry. Policies that promote fossil fuel production also threaten the industry as investors are swayed by the profitability of such investments. In order to change this situation, more policies should be put in place to encourage public/private partnerships that could help move the industry (Valdivia et al., 2016). Researchers could also put on more efforts in coming up with ways in which industrial challenges could be addressed and how every stakeholder could be included to benefit the industry (Dale, 2018). With reference to the strong points, the bioenergy industry could be able to improve the rural livelihoods by promoting enterprise development and employment opportunities. The government could therefore support the industry by encouraging public/private partnerships and correcting unfavorable tax regimes.

From the challenges and the opportunities existing in the bioenergy industry as noted from key informant interviews and the literature reviewed, commercialization pathways were thus proposed as follows:

(1) Establish public-private partnerships in the bioenergy sector. Partnerships could be at any level; local (user) level where local entrepreneurs partner with each other, fabricator level and institutional level which include researchers and policy makers. Partnerships at the local level are especially good when entrepreneurs want to share the investment costs. It allows a sense of ownership of the enterprise such that every party involved in the partnership would work towards ensuring the success of the enterprise. The government could establish national bioenergy policies and strategies that would help push the development of commercial bio-industries. Collaboration of all the stakeholders (industry, small-medium entrepreneurs, academia and NGOs) is especially important in ensuring a synchronized benefit is achieved in the sector. The government could partner with the local innovators in the bioenergy and create incentives for the growth of the sector. Partnering with other sectors like the biomass production sector would also be important in providing raw materials for the enterprises. Fabricators could ensure that the technologies are simpler to use and would require minimal costs of repair and maintenance to attract more investment. An effective feedback mechanism could also be designed between user of the technologies and fabricators to ensure information flow regarding the suitability and viability of the technologies to the users. This would help in improvement on the designs of the technologies to make them more user friendly. Research institutions could partner with industries to ensure a collaborative effort is put to disseminate the technologies

Table 2. SWOT analysis of a bioenergy enterprise.

Strengths (Internal)	Weaknesses (Internal)
Supply of clean energy and reduced carbon emission. There is an urgent need for technologies that would increase climate change resilience. There is thus an increase in advocacy for sustainable solutions to climate change	Technology complexity especially for commercial levels
Promoting sustainable agricultural systems by encouraging all year-round production of feedstock e.g. corn for corncobs to ensure constant biomass supply	High capital and operation costs
Improving rural livelihoods by promoting enterprise development	Knowledge gap between laboratory and field/factory operations
Job creation enhancing economic development	Land use conflicts- land use for food production vs land use for technology feedstock production
Creating an environment for continuous technological improvement	It is difficult to get capital to invest in demonstrations before deploying the technology
Contribution to scientific knowledge	Minimum stakeholder engagement
Opportunities (External)	Threats (External)
There are advocacies in place for reduced carbon emission	Records of failed investments in the industry which discourage potential investors
Climate smart agriculture agenda at the forefront	High capital and operation costs for demo plants and commercial operations
Opportunities for job creation and employment	Policy issues that continue to boost non-renewable energy
Opportunities for scientific knowledge creation	Constant change in technological innovation processes
Increased awareness on bioenergy technological innovations	Unreliable response from potential investors
Increased push to exploit the countries natural resources	Inconsistent climate patterns that threaten biomass production

Source: Primary Data Collection (2022).

to the targeted users effectively.

(2) Simplify the designs of bioenergy technologies. One challenge that would limit commercialization of technologies is a complex design that would not be applicable at entrepreneur level. Such complexities come with huge capital costs of construction as well as operations. Investors require easy to handle technologies that would not see them increasing their capital expenditure and thus reducing the revenue earnings. While targeting local entrepreneurs, the designs should be made in a manner easily understandable to the entrepreneurs for them to appreciate its value. That would spur interest from other entrepreneurs who would then create a chain of investment

promoting the spread of the technology to the wider population.

(3) Investing in Research and Development (R&D). Research and development allows for a continuous improvement on the technological designs by researchers or innovators. This allows an opportunity to realize faults that may exist on prototypes and mend them before deploying technologies to the outside population which could accelerate the development of the industry. Technological improvements allow technologies to be user friendly and more replicable among adopters. Therefore, government, investors and other stakeholders could channel more funds towards research and development for the

improvement of the sector.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Overall, the study reveals that bioenergy is a promising industry which could replace the fossil fuels and facilitate economic growth, infrastructural development, and social wellbeing of communities if properly utilized. The bioenergy industry could offer a great relief in energy supply across the country even though a number of barriers still exist that hinder its full utilization, for example, lack of properly targeted policies, technical and

financial constraints. However, the positive impacts of bioenergy could continue to be enjoyed if certain considerations are put in place. For instance, the technologies could be made simpler to suit a common user, that is, the operational complexities of the technologies could be reduced to be friendlier to the small-medium entrepreneurs who wish to invest in the industry. Designing these technologies to better utilize the secondary benefits that come with their implementation to generate additional income could be a way to ensure sustainability. These co-benefits also increase investment interest in cases of slow return on investment.

Stakeholders from all the relevant sectors like policy, environment and market chains are therefore called upon to collaborate to effectively develop an industry that is sustainable. Research institutions could help with identifying the technological complexities that may hinder adoption and rectify them before dissemination. Relevant policies and strategies could also be put in place in order to ensure that the bioenergy industry is competitive in the world energy mix.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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