International Journal of Managerial Studies and Research (IJMSR)
Volume 11, Issue 6, June 2023, PP 52-64
ISSN 2349-0330 (Print) & ISSN 2349-0349 (Online)
https://doi.org/10.20431/2349-0349.1106006
www.arcjournals.org

Economics of Briquettes and Charcoal Production Technologies in Kenya: Implication for Wide-scale Commercialization

Lilian Achieng Onyango[1], Daudi M. Nyaanga[2]

[1]*Department of Agricultural Economics and Agribusiness Management, Egerton University, Egerton-Njoro, Kenya*
[2]*Department of Agricultural Engineering, Egerton University, Egerton-Njoro, Kenya*

Corresponding Author: *Lilian Achieng Onyango, *Department of Agricultural Economics and Agribusiness Management, Egerton University, Egerton-Njoro, Kenya*

Abstract: *This study evaluated the economic viability of investing in improved briquettes and charcoal production technologies among small-medium entrepreneurs. Specifically, the study estimated the cost of briquette and charcoal production using improved production technologies and determined the feasibility of the projects using specific economic indicators. The cost of production comprised of fixed, operations and maintenance costs estimated from the current market prices and based on different assumptions. Economic analysis revealed that unit costs of briquette production using drum agglomerator and screw press technologies were KES.10.6 and KES. 17.83 per kg respectively, while production costs for charcoal were KES.27.79 and KES. 35.60 per kg when using vertical and horizontal drum kilns at a proposed selling price of KES. 40 and KES. 50 per kg respectively. The study recorded positive net present values for briquette and charcoal production using all the technologies. The highest net present value was recorded from drum agglomerator and vertical drum kiln technologies for briquettes and charcoal production respectively. Study findings reveal that production of briquettes and charcoal using the improved technologies is economically viable. The study gives a new direction to energy policy which could spur more interest among entrepreneurs willing to invest in the bioenergy sector.*

Keywords: *biomass briquettes; charcoal; bioenergy technologies; economic feasibility; net present value; Kenya*

Abbreviations: *KCSAP-Kenya Climate Smart Agriculture Project, NPV-Net Present Value, IRR-Internal Rate of Return, PBP-Payback Period, KES-Kenya shilling, USD-Dollars (USA)*

1. Introduction

There is urgent need to develop innovative technologies and energy sources that would help replace and reduce the use of fossil fuels thereby reducing greenhouse gases emissions. However, the development of these technologies must be viable economically and environmentally to ensure sustainability. In this perspective therefore, the question lies on whether the new technologies are able to overcome economic challenges especially those affecting small-medium entrepreneurs. In this regard, bioenergy is gaining awareness and has contributed substantially to meeting the rapidly growing demand for energy globally (Kundu *et al.*, 2018). Approximately 3 billion people depend on wood as their prime energy source for domestic use (Muazu&Stegemann, 2015). The Kenyan biomass fuel industry has dominated the energy sector providing nearly 68% of the total country's energy requirement as well as 98% of the rural household energy requirement (Iiyama *et al.*, 2014; Mugo & Gathui, 2010). Charcoal and woodfuel make up to 70% of the total biomass energy sources that is required for heating and cooking (Karekezi *et al.*, 2012).

Studies show that approximately 7.2 million households in Kenya use biomass as the main energy source with charcoal making up to 13.3% and woodfuel 68.7%. Only a small fraction of the Kenyan households uses alternative energy sources like paraffin, liquefied petroleum gas (LPG) and electricity for cooking and heating which is approximated at 1.6 million households (Wiesmann, 2016). Nearly 45% of the total biomass energy resource is from the forests and woodlands which takes approximately 7% of the country's land (MEWNR, 2013). The remaining biomass is provided by the farmlands which also provides agricultural crop and animal wastes (Kiruki *et al.*, 2019).

Overreliance on wood fuel as major source of household energy has facilitated rapid increase in environmental degradation especially in rural communities (Jewitt*et al*., 2020). This has resulted in alarming decline in forest land which is accelerating the effects of climate change through increased quantities of greenhouse gases in the atmosphere (Joseph & Kaswamila, 2017). Any mitigation measure that would ensure reduction in the use of forest trees as a source of energy is important (Mutugi & Kiiru, 2015). Baringo is one of the counties in Kenya with numerous charcoal entrepreneurs. There is need to develop technologies that would ensure charcoal is produced sustainably ensuring good health and environmental protection (Hamid & Blanchard, 2018).

Charcoal in Baringo is produced from *Prosopis juliflora* (Mathenge) and *Acacia tortilis* (Umbrela thorn) which are preferred for their ability to burn for a longer period (Dato *et al*., 2019), making Baringo charcoal more marketable. Approximately 97 percent of the households that practice charcoal production majorly use earth mound kilns (Mieke *et al*., 2020). These are in most cases inefficient, and produce a lot of smoke that increases the levels of air pollution. It is noted that 99% of Kenyan charcoal producers and 100% of Baringo county producers mainly rely on the traditional kilns for their production which are inefficient, yielding less output in relation to the amount of biomass invested (Mutimba & Baraza, 2005; Ndegwa *et al*., 2021).The traditional earth kilns have a very low efficiency of 15-20% taking approximately 5-10 days for complete carbonization (Oduor *et al*., 2006; Ruuska 2012) with lot of wood material being used as the carbonation process tend to be slow.There has been limited use of modern and improved technologies in the production of charcoal. This pose a lot of health risks including risk of stroke, kidney diseases as well as pneumonia in children (Weihold, 2011; Barnes, 2014), thus the need to produce charcoal more efficiently and sustainably.

Biomass briquettes production is also an effective way to achieve clean and sustainable energy which in turn would enhance the promotion of clean and sustainable cooking enhancing the realization of SDG 7 on clean and affordable energy (UNDP, 2015). Briquette uses charcoal dust and thus promotes a form of cyclic economy in which waste products are used as raw material to produce a more useful product. It also uses locally available agricultural wastes such as rice husks, coconut husks, corn cobs, waste papers and plant residues as raw materials which would greatly reduce reliance on wood as a prime fuel source. Biomass briquette presents an opportunity for cheap and clean energy producing quality fuel, generating income and creating employment opportunities especially for the youths (Vivek*et al*., 2019). It also provides an alternative to electricity or liquid petroleum gas (LPG) which are costly especially for rural households and small-medium enterprises (Bot *et al*., 2022).

Egerton University developed improved charcoal and briquettes making technologies which were disseminated to various producer groups in Baringo county. These include screw press and drum agglomerator for briquette making and vertical and horizontal drum kilns for charcoal production presented in figures 3 and 4 in Appendix 1. Through Kenya Climate Smart Agriculture Project Bioenergy Value Chain Project in Baringo, the university anticipated to contribute to mitigation of effects of climate change through the use of improved charcoal and briquettes making technologies, shifting the community from the conventional charcoal and briquettes production techniques. These technologies are efficient compared to the traditions charcoal and briquette production methods since they are able to convert the smoke released during carbonization into wood vinegar. This therefore not only helps to reduce the amount of carbon emission but also improve agricultural production as wood vinegar can be used as a pesticide in crops. Despite the introduction of the technologies, there is limited information on the economics of these technologies for charcoal and briquettes production. This study therefore, sought to analyze the economic viability of briquette and charcoal production of a small-medium entrepreneur using these technologies. The objectives of the study were; i) to estimate the cost of briquettes and charcoal production using improved briquetting and charcoaling technologies and ii) to determine the feasibility of the projects using specific economic indicators. The study hypothesized that production of briquettes and charcoal using the improved technologies is profitable and economically viable.

The study provides necessary knowledge required to improve the bioenergy sector's competitiveness in the country. It will enable entrepreneurs make informed choices on investing in the industry. This study may also lead to increased adoption of improved charcoal and briquette making technologies which may result in improved sources of income, employment and process and product development in the bioenergy sector.

2. METHODOLOGY

2.1. Study Area

This study was carried out in Baringo county which is located in Northern Kenya in the Rift Valley region and is a major charcoal producing region in the country with most parts classified as arid and semi-arid. The county covers an area of 11,075.3 km^2 with a population of 666,766 and a population density of 60/km^2 (160/sq mi) (KEBS, 2019). It sited 250km west of Nairobi with an altitude of 1067m above sea level. It receives annual rainfall range of 1000mm – 1500mm in the highlands and 300-700mm in the lowlands per year with a mean monthly temperature of 32.8°C ± 1.6°C. Baringo borders Turkana and Samburu counties to the North, Laikipia to the East, Nakuru to the South, Elgeyo-Marakwet and West Pokot to the West.

Charcoal production is one of the main economic activities in Baringo with approximately 93.7% of the households engaged in its production (Ndegwa *et al*., 2021). 4 research sites were selected for the study including; GEWC Benoin Charcoal and Briquette Producers in Eldama Ravine, NIB Marigat group, Ilangua Group in Chemoigut and Loboi Charcoal Burners group in Loboi. Production sites were purposively selected from the producer groups' locations where charcoaling and briquetting machines had been disseminated by the KCSAP Bioenergy value-chain project from Egerton University. This project was a component of KCSAP that sought to support interventions that promote uptake of improved technologies in the bioenergy value chain. These technologies act as avenues to help reduce carbon gas emissions, thus promoting climate change mitigation agenda.

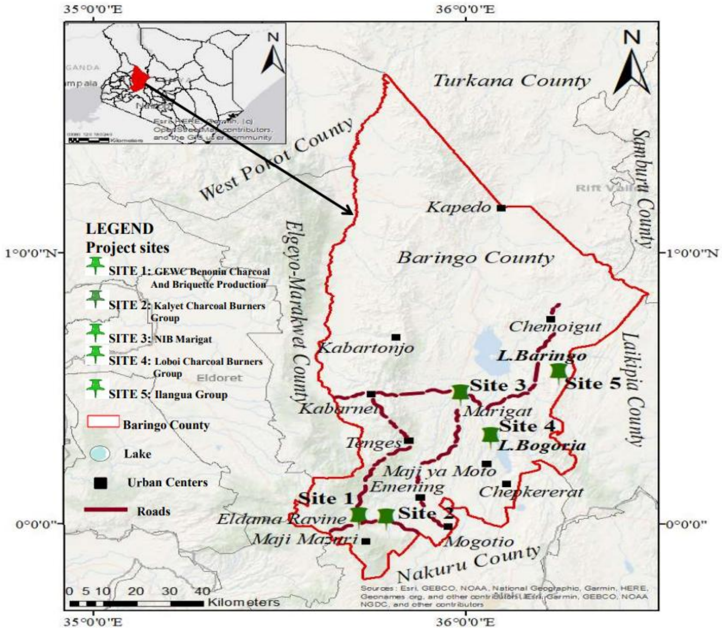


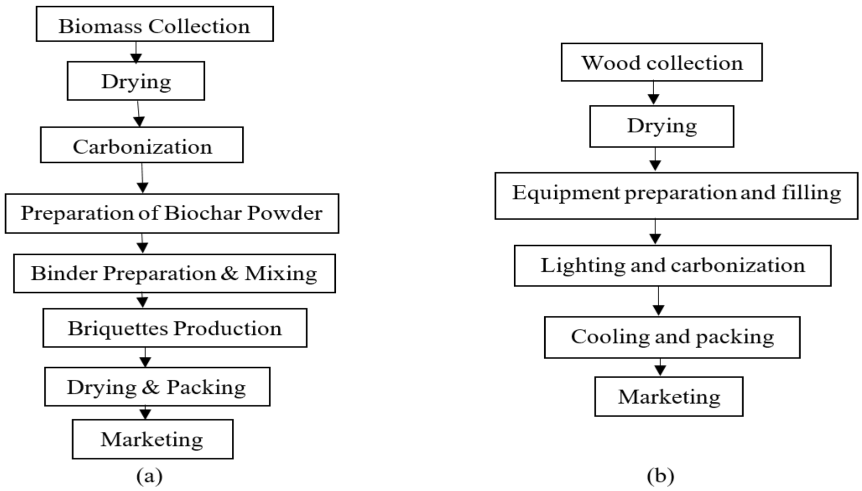
Figure1. *Map of Baringo county showing study sites*

2.2. Data Collection

The study was an off-lab analysis by the end-users of the technologies (charcoal and briquette entrepreneurs). Corncobs were used as the major agricultural waste raw material in briquettes development. The raw materials were obtained from farmers' fields and NIB, Marigat for their availability in large quantities after maize harvesting. Briquettes development follows a systematic process as shown in Figure 2. The corncobs were dried to a moisture content of 8-12% (Ajimotokan *et al*., 2019). The dried corncobs were then carbonized in a drum kiln to obtain biochar that would then be crushed and densified to form briquettes. To develop the briquettes using screw press, 5kg of biochar was weighed and molasses (used as the binder) sprinkled on it. This mixture was fed to the screw press for briquettes densification. For briquettes development using drum agglomerator, biochar was poured on to the drum and molasses sprinkled on top of the biochar as the drum rotated in the ratio of 6:1 for biochar to molasses. This was done until the briquettes granules grew to the desired sizes an approach that was used by Jamradloedluk and Wiriyaumpaiwont (2007). The formed spherical briquettes were then removed by hand and dried under shadow to avoid direct sunlight which would lead to briquettes cracking.

For charcoal production as shown in figure 2, *Prosopis juliflora* (*Mathenge*) tree was used as the feedstock, a treewhich has become invasive in the region. The invasion has resulted in the loss of natural biodiversity, reducing the land coverage for agriculture and grazing (Mbaabu *et al*., 2019). The tree species has also led to obstruction of water sources in the region as well as increasing farming costs as farmers incur labour costs to clear the invaded cropping land (Eschen *et al*., 2021). Controlled use of this tree is thought to be able to control its spread thus its suitability for use in the study. Only the branches of the *Mathenge* tree was used for research purpose to avoid cutting down the whole tree. As much as *Mathenge* is an invasive tree, it still acts as a good cover in the region being that the area is categorized as a semi-arid region. The wood was cut into small sizes about 50cm to fit the drum kilns. The drum kilns were fed with 55kg and 30kg of wood for vertical drum kiln and horizontal drum kiln respectively. The kilns' fireplaces were set and the vents opened to allow in enough oxygen for carbonization for approximately 30 minutes. The fireplaces and vents were then closed for 2 ½ hours and 2 hours for vertical drum kiln and horizontal drum kiln respectively. After carbonization was complete, the vents were opened to allow offloading of charcoal.

Quantities of each input was noted and monetized to enable calculation of all the costs involved in production. Input parameters included labour, raw materials, machine and storage facility costs. The amount of labour was calculated based on the number of hours the labour was offered which was valued at a fraction of the unskilled market wage. Quantities of output was also noted and revenues earned calculated.



Figur2. *(a) Briquette and (b) Charcoal production process*

2.3. Data Analysis and Calculations

Assumptions of the Study

The capacity of the briquetting machine was 50 kg/h and 25kg/h for drum agglomerator and screw press respectively. This was derived based on the ratio of briquettes produced in kilograms to the average time taken in the production process by the briquetting machine. The machine capacity of the charcoaling technologies was 50kg/day and 90kg/day based on their sizes for vertical drum kiln and horizontal drum kiln respectively. Production time included the time the raw material was loaded into the machine, compaction/carbonization of the material for briquettes and charcoal respectively, briquette/charcoal residence and ejection from the machine. Being a new project to the entrepreneurs, the economic life of the technologies was assumed to be 5years.

The operation time of the technologies was assumed to be 8hours per day. The total number of operating days will be 240 days per year signifying 66% utilization capacity. A discount rate of 10% was assumed based on Pradhan *et al*. (2019). This is also in line with the global discount rate trend as mentioned by Kpalo *et al*. (2022) which lies closely to the CBK weighted average rates of 10.81 as at the time of the study. This is the current accepted rate used by most global approaches. A depreciation of 10% was assumed on the initial investment which was calculated using the straight line method following Kaoma and Gheewala, (2021) approach. The repair and maintenance cost of the machinery is generally assumed to range from 10-15% of the total cost of the machine operation and this normally increases as the useful life of the machine increases (Oluka & Nwani, 2013; Rotz, 1985). The study thus assumed a repair and maintenance cost of 10%. A price of KES.0.58/kg was assumed for the raw biomass material based on the projected cost of agricultural residues of USD 5/ton as found by Gujba *et al*. (2015). This cost was based on the annual growth rate of 0.1% from the US Energy Information Administration and may remain so until 2030 (EIA, 2021). A selling price of KES. 50 per kilogram was proposed for briquettes and KES. 2300 for 90kg/bag based on the current market prices.

Economic Feasibility Analysis

Feasibility indicators used in this study included; net present value (NPV), internal rate of return (IRR) and payback period (PBP) as shown in table 1.

Table1. *Economic indicators for the feasibility analysis*

Economic indicator	Definition	Equation
Net Present Value	It denotes the present value of all future benefits minus the present value of cost required to invest.	$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - I_0$
Internal Rate of Return	The discounted rate that makes the net present value of the future net benefits equals the initial investment. It denotes the highest interest rate that would be paid by a project for all the resources that were used in the project if it wanted to recover its investment cost as well as the cost of operations and still make a profit	$\sum_{t=1}^{n} \frac{R_t}{(1+i)^t} - I_0 = 0$
Payback Period	The period it will take from inception of a project to recovery of the total investment cost.	

Source: *Walekhwa et al.(2014). Where R_t is the Net cash flow at time t, i is the discount rate, t is time of the cash flow and I_0 is the initial investment.*

3. Results and Discussions

3.1. Cost of Charcoal and Briquettes Production

The total production cost of briquettes and charcoal comprises fixed costs, operations costs and the cost of repair and maintenance. Fixed costs are the costs of the briquetting and charcoaling technologies, installation costs and the cost of the storage facility. Operation and maintenance costs include the cost of raw materials and processing including their transportation cost. Included in the operation and maintenance costs are the cost of labour, repair and maintenance. Machine cost accounts for the largest share of fixed costs for the briquetting and charcoaling technologies i.e. drum agglomerator and screw press (briquetting technologies) and vertical drum kiln and horizontal drum kiln (charcoaling technology). Raw material costs accounts for the largest share of the operation costs for all the technologies.

3.1.1. Cost of Charcoal Production

In Table 2, the total cost of charcoal production using vertical drum kiln is detailed. The total cost of production was also estimated from the capital expenditure and operations/maintenance expenditure. Machine cost (KES. 110,000) accounts for the largest share of fixed cost while raw material cost (KES. 183,744) accounts for the largest share of operations and maintenance costs. A total of KES. 600,331.20 was the investment cost to produce 90kg bag of charcoal per day for 240days. Table 3 also presents the results for the production cost of charcoal using horizontal drum kiln. The drum has a capacity of producing 50kg of charcoal per day. For the drum kiln, the largest share of fixed cost was taken by the machine cost (KES. 30,000) whereas the cost of raw materials and processing accounted for the largest share of operation cost (KES. 231,360). A total of KES. 427,128 was the initial investment cost enough to produce 50kg bag of charcoal per day for 240days.

Table2. *Total Cost of Charcoal Production for Vertical Drum Kiln at utilization capacity of 90Kg/day*

Item	Rate (KES)	Amount (KES)
(A) Fixed Cost (Initial Investment)		
A1.Machine cost	110,000	110,000
A2. Installation cost	1,500	1,500
A3.Storage facility cost	75/day×240days	18,000
Sub-total		129,500
(B) Operation Cost		
B1. Raw material cost	765.6/day×240days	183,744
B2. Raw material processing cost	500/day×240days	120,000
B3. Labour cost	500/day×240days	120,000
B4. Depreciation cost	10% of Initial Investment (A)	12,950
B5. Miscellaneous cost	5% Sum of (B1;B2;B3)	21,187.2
Sub-total		457,881.2
(C) Repair and Maintenance cost		
C1. Repair and maintenance cost	10% of Initial Investment (A)	12,950
Sub-total		12,950
Total Investment Cost		**600,331.2**

Source: *Primary data collected, 2022*

Table3. *Total Cost of Charcoal Production for Horizontal Drum Kiln at utilization capacity of 50Kg/day*

Item	Rate (KES)	Amount (KES)
(A) Fixed Cost (Initial Investment)		
A1.Machine cost	30,000	30,000
A2. Installation cost	500	500
A3.Storage facility cost	75/day×240days	18,000
Sub-total		48,500
(B) Operation Cost		
B1. Raw material cost	464/day×240days	111,360
B2. Raw material processing cost	500/day×240days	120,000
B3. Labour cost	500/day×240days	120,000
B4. Depreciation cost	10% of Initial Investment (A)	4,850
B5. Miscellaneous cost	5% Sum of (B1;B2;B3)	17,568
Sub-total		373,778
(C) Repair and Maintenance cost		
C1. Repair and maintenance cost	10% of Initial Investment (A)	4,850
Sub-total		4,850
Total Investment Cost		**427,128**

Source: *Primary data collected, 2022*

3.1.2. Cost of Briquettes Production

The cost of producing briquettes comprised of fixed costs, operations and maintenance costs (variable costs) as detailed in Table 10 in Appendix 2. The cost of the machine accounts for the largest share of fixed cost for both the drum agglomerator (KES. 150,000) and screw press (KES. 100,000) whereas the cost of raw materials (KES. 252,596.80) and electricity cost (KES. 240,000) accounts for the largest share of operations and maintenance costs for drum agglomerator and screw press respectively. The total cost of investment to produce 50kg/h and 25k/h of briquettes for a total of 240days was KES. 1,017,776.64 and KES. 855,928.32 using drum agglomerator and screw press respectively.

Briquettes production using the two machines requires a stable power supply for a maximum production efficiency. It is also to be noted from the results in Table 1 that raw materials account for a considerable share of the operation costs for both machines. For a successful briquette enterprise, the availability of raw materials should be considered a priority (Felfli *et al*, 2011). The economics of any bioenergy enterprise is site-specific depending on the local conditions, thus, the enterprise requires close proximity to the source of raw materials. Baringo has abundant agricultural residues which are generated from the agricultural activities especially from Pekerra Irrigation Scheme. These residues could potentially be utilized to produce sustainable bioenergy.

3.1.3. Cost of Producing a Unit of Charcoal/Briquette

The cost of producing a unit of briquette and charcoal and the annual revenue that could be generated from the sale of charcoal/briquette for the different technologies was also estimated as presented in Table 4. Given the machine capacities of 50kg/h (drum agglomerator), 25kg/h (screw press), 90kg/day (vertical drum kiln), 50kg/day (horizontal drum kiln) and selling prices of KES. 50/kg for briquette and KES. 40/kg for charcoal, the total annual revenue can also be calculated. From the results, the proposed selling prices for a unit of briquette (KES. 50 per kg) and charcoal (KES.40 per kg) are both higher than the unit costs using different briquetting and charcoaling machines. This result is consistent with the results of Kpalo *et al*. (2022), where the unit cost for producing composite briquettes was USD 0.16 and the proposed selling price was USD 0.26 which was higher than the unit cost. This result however contrasts with the result of Kaoma and Gheewala (2021), whose unit cost of producing briquettes was higher than the proposed selling price. With the machines being operated for 240 days, 96000kg and 48000kg of briquettes will be produced for drum agglomerator and screw press respectively whereas, 240 bags (21600kg) and 12000kg of charcoal will be produced from vertical drum kiln and horizontal drum kiln respectively per year. Based on this, the annual revenue generated for the first year and subsequent years was estimated to be KES. 4,800,000, KES. 2,400,000, KES. 864,000 and KES. 480,000 for drum agglomerator, screw press, vertical drum kiln and horizontal drum kiln respectively.

Table4. *Cost of Producing a Unit of Briquette and Charcoal and Annual Revenue*

Items	**Amount (KES)**			
	Drum agglomerator	**Screw press**	**Vertical Drum Kiln**	**Horizontal Drum kiln**
Total Investment cost (KES/year)	1,017,776.64	855,928.32	600,331.2	427,128
Unit Cost (KES/kg)	10.6	17.83	27.79	35.60
Annual revenue (KES/year)	4,800,000	2,400,000	864,000	480,000

Source: *Primary data collected, 2022*

3.2. Profitability Analysis of Briquette and Charcoal Production

Upon cessation of any business, the revenue obtained from the sale of all the business assets at that particular time is expected to be higher that the investment that was made (Vochazka *et al*., 2019). Thus, an economic analysis is important in determining the feasibility of any enterprise (Ifa *et al*., 2020). This section presents the cash inflow for each technology showing income and expenditure for a period of 5 years. The cash inflow data enabled calculation of the economic indicators for an entrepreneur engaging in briquette or charcoal production using these technologies. In Table 5, the NPV of briquetting project using drum agglomerator at capacity utilization of 66% and a discount of 10% was KES. 17,177,999.9. The positive NPV confirms financial profitability and investment viability in the briquetting project using drum agglomerator technology. Similarly, in Table 6, briquette production using screw press at a production capacity of 50kg/h would present a positive net present value indicating financial profitability and investment viability in the technology.

Table5. *NPV of Briquette Production using Drum Agglomerator*

Time (Year)	**Cash inflows (KES)**	**$(1+i)^t$ (10%)**	**PV $=C/(1+I)^t$**
1	4,800,000	1.1	4,363,636.4
2	4,800,000	1.21	3,966,942.1
3	4,800,000	1.331	3,606,311.0
4	4,800,000	1.4641	3,278,464.6
5	4,800,000	1.61051	2,980,422.4
Total present value (TPV)			18,195,776.5
Initial investment (Io)			1,017,776.64
NPV			**17,177,999.90**

Source: *Primary data collected, 2022*

Table6. *NPV of Briquette Production using Screw Press*

Time (Year)	Cash inflows (KES)	$(1+i)^t$ (10%)	PV $=C/(1+I)^t$
1	2,400,000	1.1	2,181,818.2
2	2,400,000	1.21	1,983,471.1
3	2,400,000	1.331	1,803,155.5
4	2,400,000	1.4641	1639232.3
5	2,400,000	1.60151	1,498,585.7
Total present value (TPV)			9,106,262.8
Initial investment (Io)			855,928.32
NPV			**8,250,334.50**

Source: *Primary data collected, 2022*

The capacity of the briquetting machines may have played a major role in determining the NPV of the technologies. Studies have indicated that plants with low capacity have had a negative NPV while those with large capacity had positive NPV. An example is a study done by Kaoma & Gheewala (2021), where negative NPV was reported for plants with lower capacities and a positive NPV for plants with higher capacities. This can be noted on a study done by Hakizimana& Kim (2016) where a positive NPV of USD 17.2 million which could justify its commercialization. Another related study by Sengar *et al*. (2013) noted a positive NPV of USD 25,831.88, USD 30,117.20 and USD 8434.78 for cashew shell, grass and rice husk briquette projects respectively. Other studies that noted a higher NPV include a study done by Feng *et al*. (2013) which recorded an NPV of USD 9.81 million and a study by Hu *et al*. (2014) recording an NPV of USD 1.40 million. The positive NPVs noted could then be interpreted as presenting the projects as feasible and economically viable.

In Table 7 and 8, the results of the analysis of net present value for charcoal production using vertical and horizontal drum kilns is shown. Table 7 indicates that the projected earnings from investing in vertical drum kiln charcoaling technology discounted at 10% will exceed its projected costs at today's shillings, thus assuming a profitable investment. Table 8, similarly presents a positive NPV indicating a favourable returns on investment using the horizontal drum kiln.

Table7. *NPV of Charcoal Production using Vertical Drum Kiln of Capacity, 90kg/day*

Time (Year)	Cash inflows (KES)	(1+i)t (10%)	PV =C/(1+I)t
1	360,000	1.1	327,272.7273
2	360,000	1.21	297,520.6612
3	360,000	1.331	270,473.3283
4	360,000	1.4641	245,884.8439
5	360,000	1.60151	224,787.8565
Total present value (TPV)			1,365,939.417
Initial investment (Io)			600,331.20
NPV			**765,608.22**

Source: *Primary data collected, 2022*

Table8. *NPV of Charcoal Production using Horizontal Drum Kiln*

Time (Year)	Cash inflows (KES)	(1+i)t (10%)	PV=C/(1+I)t
1	192,000	1.1	174,545.4545
2	192,000	1.21	158,677.686
3	192,000	1.331	144,252.4418
4	192,000	1.4641	131,138.5834
5	192,000	1.60151	119,886.8568
Total present value (TPV)			728,501.0225
Initial investment (Io)			373,778.00
NPV			**354,723.02**

Source: *Primary data collected, 2022*

The Internal Rate of Return (IRR) for drum agglomerator, screw press, vertical drum kiln and horizontal drum kilns were 51%, 49%, 34% and 30% respectively as shown in Table 9. From the cash flows of the briquetting and charcoaling projects, the NPVs would be equal to zero at the aforementioned discount rates. A negative NPV will be obtained if the interest rate goes above the IRRs. This implies that profits to be attained would be much less than the investment cost. An investment will be deemed profitable and economically viable if the value of IRR is greater than the allowed discount rate (Walekhwa *et al*., 2014). In related studies, Hu *et al*. (2014) obtained an IRR of 36% with a 4.4 years' payback period. When analyzing cost-benefit of charcoal briquette production, Onchieku (2018) noted IRR values of different setups; 68%, 76%, and 100% over a two-year production using a discount rate of 15%. These values were all greater than the discount rate value signifying profitable investments. The Payback Period (PBP) for drum agglomerator, screw press, vertical drum kiln and horizontal drum kiln was found to be 1year, 1year, 1.67years and 1.95years respectively. This implies that for all the projects, it will not take a lot of time to get returns on investment.

Table9. *Analyzing Economic Indicators of Feasibility of Briquetting and Charcoaling Projects*

		Drum agglomerator	Screw press	Vertical Drum Kiln	Horizontal Drum Kiln
S/No	**Indicator**	**Value**			
1	Net Present Value (KES)	17,177,999.90	8,250,334.50	765,608.22	354,723.02
2	Payback Period (Years)	1	1	1.67	1.95
3	Internal Rate of Return (%)	51	49	34	30

Source: *Primary data collected, 2022*

3.3. Environmental Implications of the Study

This study is not only concerned about making briquettes and charcoal production more economically profitable but also the implications their production has on the environment. Charcoal production using vertical drum kiln will require 1.83 tonnes of wood to produce 1tonne of charcoal. This is lower than the amount of wood (5 tonnes) that was required to produce 1tonne of charcoal from a study conducted by Hakizimana and Kim (2016). This therefore indicates that charcoal production using the improved production kilns significantly reduces the amount of wood used thus lowers the amount of forests lost. Carbon emissions are also reduced as the kilns are made in such a way to convert the smoke released during carbonization into smoke water (wood vinegar) thus contributing to reducing global warming. Briquette on the other hand can also be produced from agricultural waste materials which greatly reduces the use of forest wood and thus reducing deforestation.

4. Conclusions And Recommendations

Economic feasibility analysis using cost-benefit criterion allows aggregation and comparison of positive and negative consequences of investments in monetary terms. These include the monetized costs involved in the investment and revenues gained. In this study, CBA was used as a decision tool to show feasibility of investing in improved briquetting and charcoaling technologies. From the study findings, it can be concluded that investing in improved bioenergy technologies is economically feasible and would be a good venture for small-medium enterprises who wish to expand their businesses taking consideration to environment.

Developing technologies that are economically viable especially for small-medium entrepreneurs would attract more investors into the bioenergy value chain. This would also stimulate more innovations towards bioenergy sector which would help mitigate energy insecurity in Kenya. A new direction to energy policy can thus be proposed based on the positive economic analysis of the projects done. The government could invest more in the renewable energy sector to attract more attention from those who would wish to get into bioenergy business. Its support could also be needed to put in place low interest rates to enable easier financial access to those entrepreneurs who would wish to borrow loans from financial institutions. Government could also facilitate the development of local bioenergy factories to spur more interest from local communities to invest in the sector. Innovators could continue to evolve briquetting and charcoaling technologies to make them as economical as possible. The study limited its scope to analyzing cost-effectiveness of four briquetting and charcoaling technologies, a comprehensive analysis could be proposed to compare the economics of these technologies and the conventional production technologies. Further research could also be done on the indirect benefits that could be obtained using these charcoal and briquette production technologies.

ACKNOWLEDGEMENT

The authors sincerely acknowledge MCF@RUFORUM through TAGDev project and Kenya Climate Smart Agriculture Project at Egerton University for the financial support offered to undertake this research.

REFERENCES

Ajimotokan, H.A., Ehindero, A.O., Ajao, K.S., Adeleke, A.A., Ikubanni, P.P., &Shuaib-Babata, Y.L. (2019). Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. *Scientific African*, *6*, e00202.

Barnes, B. R. (2014) Behavioral Change, Indoor Air Pollution and Child Respiratory Health in Developing Countries: A Review. *International Journal of Environmental Research and Public Health*, *11*, 4607–4618.

Bolaji, B. (2012). Effects of unsustainable use of biomass energy for cooking and strategies for their reduction in developing countries. *Developing Country Studies*. *2*(3), 19–25.

Bot, B.V., Axaopoulos, P.J., Sakellariou, E.I., Sosso, O.T., &Tamba, J. G. (2022). Energetic and economic analysis of biomass briquettes from agricultural residues. *Applied Energy*, *321*, 119430.

Dato, N., Long, A., Sam, A., Santiago, A., Margot, H., &Gershenson, J. (2019). Charcoal distribution chain in Kisumu, Kenya. *Global Humanitarian Technology Conference (GHTC)* (pp. 1-6). https://ieeexplore.ieee.org/abstract/document/9033024

Dairo, O.U., Adeleke, A.E., Shittu, T., &Ibrahim, N.A. (2018). Development and Performance Evaluation of a Low-Cost Hydraulic-Operated Biomass Briquetting Machine. *FUOYE Journal of Engineering and Technology*, *3*, 1–6.

Energy Information Administration. Analysis & Projections-U.S. Energy Information Administration (EIA). Available online: https://www.eia.gov/analysis/

Eschen, R., Bekele, K., Mbaabu, P. R., Kilawe, C. J., & Eckert, S. (2021). Prosopis juliflora management and grassland restoration in Baringo County, Kenya: Opportunities for soil carbon sequestration and local livelihoods. *Journal of Applied Ecology*, *58*(6), 1302-1313

Felfli, F. F., Mesa, P. J. M., Rocha, J. D., Filippetto, D., Luengo, C. A.,&Pippo, W. A. (2011). Biomass briquetting and its perspectives in Brazil. *Biomass Bioenergy*, *35*, 236–242.

Feng, C., Yu, X., Tan, H., Liu, T., Hu, T., Zhang, Z., Qiu, S.,& Chen, L. (2013). The economic feasibility of a crop-residue densification plant: A case study for the city of Jinzhou in China.*Renewable and Sustainable Energy Reviews*, *24*, 172–180.

Hakizimana, J.D.K., &Kim, H.T (2016). Peat briquette as an alternative to cooking fuel: A techno-economic viability assessment in Rwanda. *Energy*, *102*, 453–464.

Hamid, R. G., & Blanchard, R. E. (2018). An assessment of biogas as a domestic energy source in rural Kenya: Developing a sustainable business model. *Renewable Energy*, *121*, 368–376. https://doi.org/10.1016/j.renene.2018.01.032

Hu, J., Lei, T., Wang, Z., Yan, X., Shi, X., Li, Z., He, X., &Zhang, Q. (2014). Economic, environmental and social assessment of briquette fuel from agricultural residues in China–A study on flat die briquetting using corn stalk. *Energy*, *64*, 557–566.

Ifa, L., Yani, S., Nurjannah, N., Darnengsih, D., Rusnaenah, A., Mel, M., Mahfud, M., &Kusuma, H.S. (2020). Techno-economic analysis of bio-briquette from cashew nut shell waste. *Heliyon6*(9), e05009. https://doi.org/10.1016/j.heliyon.2020.e05009

Jewitt, S., Atagher, P., & Clifford, M. (2020). "We cannot stop cooking": Stove stacking, seasonality and the risky practices of household cookstove transitions in Nigeria. *Energy Research & Social Science*, *61*, 101340. https://doi.org/10.1016/j.erss.2019.101340

Joseph, L., &Kaswamila, A. (2017). The pastoralists' resilience and innovative adaptation strategies on impacts of climate change in rangelands of Longido District, Tanzania. *International Journal of Environment and Bioenergy*, *12*(1), 47-61

Kaoma, M. &Gheewala, S.H. (2021). Techno-economic assessment of bioenergy options using crop and forest residues for non-electrified rural growth centres in Zambia. *Biomass Bioenergy*, *145*, 105944.

Karekezi, S., Mcdade S., Boardman, B., &Kimani, J. (2012). Energy, poverty and development. Toward A Sustainable Future. *Global Energy Assessment*, 151-190. doi: 10.1017/CBO9780511793677.008

Kiruki, H., Zanden, E., Zagaria, C., &Verburg, P. (2019). Sustainable woodland management and livelihood options in a charcoal producing region: An agent-based modelling approach. *Journal of Environmental Management*. *248* DOI: https://doi.org/10.1016/j.jenvman.2019.07.016

Korir, H. K. (2019). *Energy Access and Impact Analysis of Biogas Harnessing on MAU Forest Conservation* (Master's thesis, Pan African University). http://repository.pauwes-cop.net/handle/1/315

Kpalo, S.Y., Zainuddin, M.F., Manaf, L.A., Roslan, A.M., & Nik Ab Rahim, N.N.R. (2022). Techno-Economic Viability Assessment of a Household Scale Agricultural Residue Composite Briquette Project for Rural Communities in Nigeria. *Sustainability*, *14*(15), 9399. https://doi.org/10.3390/su14159399

Mbaabu, P. R., Ng, W. T., Schaffner, U., Gichaba, M., Olago, D., Choge, S., ... & Eckert, S. (2019). Spatial evolution of Prosopis invasion and its effects on LULC and livelihoods in Baringo, Kenya. *Remote Sensing*, *11*(10), 1217. https://doi.org/10.3390/rs11101217

Mieke, B., Phosiso, S., Mary, N., Grace, K., Moses, K., Siko, I., Jonathan, M., & Otieno E. (2020). *Towards sustainable charcoal production and trade in Baringo County (Vol.293)*. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/007719

Muazu, R. I., &Stegemann, J. A. (2015). Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs. *Fuel Processing Technology*, *133*, 137–145. https://doi.org/10.1016/j.fuproc.2015.01.022

Mugo, P. W. (2013). Energy *Efficient technologies for climate change mitigation: fuel briquettes in the Ruiru municipality, Kiambu County, Kenya* (Doctoral dissertation, Kenyatta University). http://ir-library.ku.ac.ke/handle/123456789/9249

Mutimba, S. & Barasa, M. (2005). Exploring the potential for a sustainable charcoal industry in Kenya. National Charcoal Survey: *Energy for Sustainable Development Africa, Report, Nairobi* 74 p.

Mutugi, M., &Kiiru, W. (2015). Biodiversity, Local Resource, National Heritage, Regional Concern and Global Impact: The Case of Mau Forest, Kenya. *European Scientific Journal*, *1*, 681-691.

Ndegwa, G., Sola, P., Siko, I., Kirimi, M., Wanjira, E. O., Koech, G., ... &Njenga, M. (2021). The charcoal value chain in Kenya: Actors, practices and trade flows in selected sites.

Obi, O.F., Akubuo, C.O., &Okonkwo, W (2013). Development of an appropriate briquetting machine for use in rural communities. *International Journal of Engineering and Advanced Technology*. *2*(4), 578–582.

Oluka, S.I., &Nwani, S.I. (2013). Models for Repair and Maintenance Costs of Rice Mills in South-eastern States of Nigeria.*Journal of Experimental Research*, *1*, 10–15.

Onchieku, J.M. (2018) Cost Benefit Analysis of Making Charcoal Briquettes Using Screw Press Machine Locally Designed and Fabricated. *International Advanced Research Journal in Science, Engineering and Technology*, 5, 57–65

Pradhan, P., Gadkari, P., Mahajani, S.M.,& Arora, A. (2019). A conceptual framework and techno-economic analysis of a palletization-gasification based bioenergy system. *Applied Energy*, *249*, 1-13.

United Nations Development Programme. Goal 7: Affordable and Clean Energy. 2015. Available online: https://www.undp.org/sustainable-development-goals#affordable-and-clean-energy (Accessed on 20 August 2022).

Vivek, C. P., Rochak, P. V., Suresh, P. S., & Kiran, K. R. R. (2019). Comparison study on fuel briquettes made of eco-friendly materials for alternate source of energy. *IOP Conference Series: Materials Science and Engineering*, *577*(1), 012183. IOP Publishing.

Vochozka, M., Rowland, Z.,&Suler, P. (2019). The specifics of valuating a business with a limited lifespan. *AD ALTA: Journal of Interdisciplinary Research*,*9*(2), 339–345.

Weinhold B (2011). Indoor PM pollution and elevated blood pressure: cardiovascular impact of indoor biomass burning. *Environmental Health Perspectives*. *119*(10), 442. DOI: 10.1289/ehp.119-a442b.

APPENDICES

Appendix 1: Egerton University Charcoaling and Briquetting technologies

(a) (b)

Figure3. *Charcoaling Technologies (a) Vertical Drum Kiln (b) Horizontal Drum Kiln*

(a) (b)

Figure4. *Briquetting Technologies (a) Drum Agglomerator (b) Screw Press*

Appendix 2: Cost of Briquettes Production

Table10. *Total Cost of Briquettes Production for Drum Agglomerator and Screw Press at production capacity of 50kg/h and 25kg/h respectively*

Item	Rate (KES)		Amount (KES)	
	Drum Agglomerator	**Screw Press**	**Drum Agglomerator**	**Screw Press**
(A) Fixed Cost (Initial Investment)				
A1.Briquette machine	150,000	100,000	150,000	100,000
A2.Installation cost	2,000	2,000	2,000	2,000
A3.Storage facility cost	12.5/h×8h/day×240days	12.5/h ×8h/day×240days	24,000	24,000
Sub-total			176,000	126,000
(B) Operation Cost				
B1. Raw material cost	131.04/h×8h/day×240days	105.52/h×8h/day×240days	251,596.8	202,598.4
B2. Raw material processing	600/day×240days	500/day×240days	144,000	120,000
B3. Labour cost	600/day×240days	500/day×240days	144,000	120,000
B4.Electricity cost	125/h×8h/day×240days	125/h×8h/day×240days	240,000	240,000
B5.Depreciation cost	10% of Initial Investment (A)	10% of Initial Investment (A)	17,600	12,600
B6.Miscellaneous cost	5% Sum of (B1;B2)	5% Sum of (B1;B2;B3)	26,979.84	22,129.92
Sub-total			824,176.64	717,328.32
(C) Repair and Maintenance cost				
C1.Repair and maintenance cost	10% of A	10% of A	17,600	12,600
Sub-total			17,600	12,600
Total Investment Cost			**1,017,776.64**	**855,928.32**

AUTHORS' BIOGRAPHY

Lilian, a Master of Science in Agri-enterprise student at Egerton University in the Department of Agricultural Economics & Agribusiness Management. She holds BSc in Agriculture (First Class) from Meru University of Science & Technology (2019). Her fields of specialization are Food security and rural development, consumer behavior, entrepreneurship, environment and climate change.

Prof Daudi M. Nyaanga, is a Professor of Energy and Processing Engineering in Department of Agricultural Engineering, Egerton University.

Citation: *Lilian Achieng Onyango & Daudi M. Nyaanga. "Economics of Briquettes and Charcoal Production Technologies in Kenya: Implication for Wide-scale Commercialization" International Journal of Managerial Studies and Research (IJMSR), vol 11, no. 6, 2023, pp. 52-64. DOI: https://doi.org/10.20431/2349-0349.1106006.*