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Cost Benefit Analysis of Making Charcoal Briquettes Using Screw Press Machine Locally Designed and Fabricated

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Abstract: The rate of deforestation and forest degradation has risen rapidly in Kenya leading to emergence of small scale and medium scale enterprises on charcoal briquetting technology for biocharcoal making for household use. However, there is lack of information on costs and benefits of making charcoal briquettes using low cost motorized screw press. This study focuses on cost benefit analysis of charcoal briquette making using locally designed and fabricated screw press machine. The parameters used to assess economic viability of making charcoal briquettes as a business are Total Investment Required, Cost of Production, Net Present Value (NPV) and Internal Rate of Return (IRR). It was found that the economic viability of briquetting technology is dependent on the type of equipment used for drying and processing materials, the type of biomass used and their physico-chemical and thermal properties and the skills of human resource both at technical and business level as well as investment capital.

Keywords: Charcoal briquettes, cost-benefit analysis, net present value, internal rate of return.

1.0 INTRODUCTION

Previous studies have shown that there are enormous quantities of forestry and agricultural biomass residues in Kenya with only ~ 10% economically exploited. These residues also contribute to environmental degradation as well as sources of human health and safety risk. Their efficient utilization for production of charcoal briquettes will contribute to reduction of deforestation by about 15% thus mitigate rate of local and global climate change.Demand for technology for briquetting biomass residues is quite high especially from small scale cottage industries. These industries usually have very high turn over of charcoal fines originating from use of charcoal in many of the hotels in various urban centres. The charcoal fines have potential of being recycled for use instead of relying on lump charcoal which is usually expensive. Attempts have been made to address previous challenges to the optimal utilization of the various biomass residues such as lack of low-cost briquetting machine and appropriate formulation of the substrate. A locally fabricated motorized briquetting machine for making briquettes for household use is currently available. However, there is need to demonstrate the efficacy of briquette making using the motorized screw press, carry out cost-benefit analysis of making briquettes using these machine, test the briquettes made for compliance to current standards and promote the adoption of briquetting technology using the motorized machine. This paper gives objectives of the study, status of the project and recommendations.

1.2 Objectives of the study

1. To assess the performance of locally designed and made screw press briquetting machines, carbonization kilns and drying stacks
2. To carry out cost benefit analysis of the screw press machine for production of briquettes, carbonization kilns and drying stacks

2.0 Methodology

A motorized briquetting machine that was designed and fabricated locally was used to assess the cost benefit analysis of making charcoal briquettes as well as carbonization kilns and drying stacks. The parameters to be used to assess economic viability of making charcoal briquettes as a business, i.e. *Business Feasibility Modelling*, are the following:

- Total Investment Required
- Cost of Production
- Net Present Value (NPV)
- Internal Rate of Return (IRR)

The tables 1, 2 and 3 show methodologies used for the calculation of various parameters on business modeling to determine investment requirements, cost of production and return on investment.

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Table 1: Business Modelling: Investment Requirement Parameter

Parameter	Units of Measure	Method
Total Investment Required, Q_{total}	KES	List each business asset, A_x, needed and calculate the total capital investment required for business assets, Q_{assets} ▪ $Q_{Assets} = \sum_x A_x$ List recurrent monthly expenditures (except for loan repayment), M_x to calculate the monthly fixed cost C_m: ▪ $C_m = \sum_x M_x$ List variable cost inputs, v_x, and calculate total variable cost C_v of 1 month production, P ▪ $C_v = P \sum_x v_x$ Calculate 1 month working capital requirement, $Q_{working}$ ▪ $Q_{working} = C_m + C_v$ Calculate Q_{total} ▪ $Q_{total} = Q_{assets} + Q_{working}$

Cost of Production

Table 1: Business Modelling: Calculating Cost of Production

Parameter	Units of Measure	Method
Cost of Production	KES / kg	Use MS Excel function (CUMIPMT) to calculate monthly loan repayment amount, C_L, based on interest rate of 15%, loan repayment period of 24 months and total amount of debt financing needed. Compute total fixed cost per unit production c_{fixed}, using C_L, monthly fixed cost, C_m, and production level, P: ▪ $c_{fixed} = (C_L + C_M) / P$ Calculate the variable cost per unit production, c_v, by summing variable cost inputs v_x ▪ $c_v = \sum_x v_x$ Calculate total per unit cost of production c_{prod}: ▪ $c_{prod} = c_{fixed} + c_v$

Return on Investment

Table 2: Business Modelling: Return on Investment Parameters

Parameter	Units of Measure	Method
NPV	KES	Project quarterly cash flows for 3 years, Q_x Use MS Excel function (NPV) to calculate net present value of investment, using discount factor of 15% ▪ $NPV = NPV(Q_1{:}Q_{12}, 15\%) - Q_{total}$
IRR	%	Project quarterly cash flows for 3 years, including the total investment Q_{total} as the first cash flow (negative) Use MSExcel function (IRR) to calculate internal rate of return: ▪ IRR = IRR(Qtotal:Q12)

3.0 RESULTS AND DISCUSSION

3.1 Briquetting Technology Assessment

The performance of key briquetting equipment is now addressed in isolation. The results and discussion cover briquetting machines, carbonisation kilns and drying racks.

3.1.1 Briquetting Machines

Five briquetting machines were fabricated and tested for the research. Of these, one is powered by electricity, the remainder are manual. At this level, there are two key design concepts: extrusion and pressing and there was a 3-2 split across these concepts. Performance is assessed in terms of production output and level of compaction.

3.1.1.1 Production Output

Table 3 shows the measured hourly output for different machines, whilst Tables 3 to 7 compare output of the same machine for 2 different feedstocks.

Table 3. Briquetting Machines - Production Output

Machine	**Feedstock**	**Output (dry basis) kg / hr**
Electrical Screw Extruder	Charcoal Dust	94
Manual Lever Press	Charcoal Dust	29
Manual Piston Extruder	Charcoal Dust	30
Manual Screw Extruder	Charcoal Dust	21

Table 4. Production Output for Electrical Screw Extruder

Feedstock	**Output (dry basis) kg / hr**
Charcoal Dust[1]	94
Carbonised Coffee Husks	106

It can be seen that electrically powered machine had a significantly higher output, at 94 kg / hr more than 3 times the fastest manual machine. The machine uses a 5HP h power motor; it is not surprising that it can do more work than 2 human operators. The manual screw extruder had the lowest output, 69% of the manual piston extruder despite having a similar cross-sectional area of output (10.4cm2 compared to 10.2cm2). It might be possible to achieve a higher output by increasing the number of output pipes or increasing the diameter of these pipes.

Surprisingly the output of the electrical screw extruder did not vary significantly between the two feedstocks tested, carbonised coffee husk had a 13% higher output, despite having a lower bulk density at only 40% of charcoal fines. It appears that the requirement to shift a greater volume of material was traded off against another factor.

The comparative rate of production results point clearly in favour of the electrical machine and since this is such an important factor for a briquetting enterprise, this may well be the best machine. The value of such an output is in the region of KES 9,400 daily, which compares favourably to typical labour rates in East Africa of approximately KES 300-500, indicating the potential viability of such a business.

It appears that the manual machines have a similar output; other factors such as compaction, capital available and reliability may become important.

3.1.1.2 Level of Compaction

The level of compaction and ultimate product density was shown to be a probable factor affecting burn performance, it will also impact on transportation costs especially when commercial rates are levied on a volume basis. Table 5 and Table 6 show that rates of compaction are relatively low, although generally higher for the electrical screw extruder.

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Table 5.: Briquetting Machines - Compaction Ratio

Machine	**Feedstock**	**Compaction Ratio**	**Briquette Density (kg/m^3)**
Electrical Screw Extruder	Carbonised Coffee Husk[2]	2.40	617
Manual Lever Press	Carbonised Coffee Husk	1.18	304
Manual Jack Press	Carbonised Coffee Husk	1.42	364
Manual Piston Extruder	Carbonised Coffee Husk	1.54	396
Manual Screw Extruder	Carbonised Coffee Husk	1.52	390

Table 6: Compaction Ratios for Electrical Screw Extruder

Feedstock	**Compaction Ratio**	**Briquette Density kg / m^3**
Carbonised Wood Shavings[3]	3.14	420
Carbonised Rice Husks[4]	3.09	560
Carbonised Coffee Husks	2.40	620
Charcoal Dust[5]	1.48	942

Comparing between machines for the same feedstock, carbonised coffee husks, the highest rate of compaction observed was for the electrical extruder. At 2.4 this is 55% more than for the best manual machine, the piston extruder. A probable reason is both the mixing action of the screw and high torque and pressure developed compared to manual efforts.

As would be expected, the ultimate briquette density depended strongly on the original density; a more dense feedstock resulted in a denser briquette. However, the compaction ratio varied somewhat in favour of bringing lighter feedstocks closer to the originally heavier feedstocks.

Nevertheless, it must be stressed that the maximum observed density of around 600 kg/m3 for virgin feedstocks is poor compared to high pressure machines; similar feedstocks yield briquette densities of 1,200 – 1,400 kg/m3 (FAO, 1990).

This would appear to be a serious limitation, especially for non-carbonised briquette production since there are good reasons to closely link burn time to briquette density. The relationship between briquette density and burn performance is a key area for future research.

Clearly the result would also appear to limit the viability of long-distance transport. In this case, the cost effectively increases on a volume basis e.g. a truck, then a briquette with half the density would cost twice as much to transport. However, the cost of transporting 'locally' may not be high compared to other costs and so any increase would not be felt so strongly.

3.1.2 Carbonisation Kilns

The performance of 4 carbonisation kilns/methods is assessed in terms of compatability with different feedstocks, the production output and efficiency.

3.1.2.1 Feedstock Compatibility

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[2] Carbonised coffee husk with cassava starch binder mixed at volume ratio (dry) 20:1
Mixture dry density: 260 kg / m^3

[3] Carbonised wood shavings with cassava starch binder mixed at volume ratio (dry) 80:1
Mixture dry density: 140 kg / m^3

[4] Carbonised rice husks with cassava starch binder mixed at volume ratio (dry) 80:1
Mixture dry density: 180 kg / m^3

[5] Charcoal fines mixed with water
Mixture dry density: 640 kg / m^3

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Table 7 shows the compatibility of the four methods with different types of materials; only the retort methods of carbonisation were suited to both large and particulate materials.

Table 7: Carbonisation Kilns - Compatability with Different Feedstocks

Kiln	**Large materials**	**Particulate**
Single Drum	Y	N
Double Drum Retort	Y[6]	Y
Open Cross-Draft Carboniser	N	Y
Open Method	N	Y

The single drum was only really suited to large materials. Without a chimney, external heating or means to improve airflow, the carbonisation process took excessively long time in the drum.

On the other hand, the retort method relies on external heating and uses a chimney to draw out volatile matter. With reservations (discussed later) this method worked for both large and particulate materials.

The open cross-draft carboniser is designed for use with particulate materials and worked effectively, the long chimney and firebox increasing production rate considerably over the drum method. Large materials would be in danger of igniting unless airflow was restricted.
The open method involved lighting materials in an open pile and carefully controlling the pryolysis process. The large surface area and unrestricted airflow enables the reaction to proceed relatively fast. In traditional charcoal making from large logs a mound is covered to prevent airflow.

3.1.2.1 Production Output & Efficiency

Table 8 compares key results for rate of return and product output for each of the methods used.

Table 8: Carbonisation Kilns - Selected Results

Kiln	**Large materials**				**Particulate**			
	Batch Size kg	**Batch Time** h:m	**% Return**	**Rate of Output** kg/hr	**Batch Size** kg	**Batch Time** h:m	**% Return**	**Rate of Output** kg/hr
Single Drum	28.5[7]	03:45	27%	1.87				
Double Drum Retort					18.5[8]	05:00	38%	1.25
Open Cross-Draft Carboniser					150.3[9]	05:35	31%	7.61
Open Method					19.0[10]	02:00	15%	1.25

The rate of return (excluding rice husks which has a high ash content) varied from 38% to 15% and it was discussed in 5.1.1.1 , the rates of return observed are fairly typical.

The highest rate of return was observed for the retort method (38%); the retort method does not directly burn any of the feedstock and so it is not surprising that the rate is so high. However, the result is somewhat misleading because a large quantity of fuel-wood (up to 20kg) had to be burnt to maintain temperatures for sufficient time. If this is factored in, the open carboniser and drum kiln performed much better.

[6] Assumed – not tested
[7] Air dry Maize Cobs
[8] Air dry Wood Shavings
[9] Air dry Coffee Husks
[10] Air dry Wood Shavings

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The open method yielded only 15%; it is likely that some of the material burnt to ash, reducing the final output. Unless rates can be improved it appears that the open method may not be viable, especially if raw material is not available in abundance.

The open carboniser gave a respectable rate of 31% for coffee husk carbonisation. This is similar to that achieved by a down-draft carboniser (33%) used in a previous study for the same feedstock (Chardust, 2004).

The rate of production varied from 1.25 to 7.61 kg / hr, with the highest rate (by some distance) achieved by the open-carboniser. However, this is considerably lower than any of the briquette machines and would present a serious challenge if any of the methods are to be used commercially.

The down-draft carboniser in the literature was reported to achieve 74kg per hour for the same feedstock (Chardust, 2004). A key reason is simply the size of the equipment: the down-draft carboniser has an approximate bed area of 60m2; the open-carboniser uses roughly $2m^2$.

The potential to scale up of these essentially experimental carbonisation techniques to achieve rates suited to commercial production, 50-100kg/hr, is another potential area for research.

3.1.3 Drying Equipment

The final area of consideration was drying equipment for which 3 methods were tried; Table 9 and Table 10 show that results were fairly similar, with briquettes taking an average of 3-4 days to dry in mixed cloud and sun conditions.

Table 9: Drying Equipment - Drying Speed

Equipment	Briquette Type	Weather	Duration of Test	% of Original Weight	% Complete	Comparative Effectiveness
Iron Sheet Tray	Carbonised Coffee Husk 3.6 cm diameter cylindrical	Cloud with Sunny intervals	2 days	72%	64%	124
Wire Mesh Tray			2 days	75%	57%	111
Polythene Sheet			2 days	78%	51%	100

Table 10: Drying Equipment – Analysis

Equipment	Capacity kg / m^2	Cost KES / m^2	Days to dry	Drying Area Needed per unit Output m2 / (kg / day)	Cost of Drying Equipment per unit Output KES / (kg / day)
Iron Sheet Tray	17.5	KES 554	3.1	0.18	KES 99
Wire Mesh Tray	17.5	KES 504	3.5	0.20	KES 101
Polythene Sheet	17.5	KES 120	3.9	0.22	KES 27

A key parameter is the drying area required for every kilogram of output. This varied from 0.18 to 0.22m2. The iron sheet was marginally the best process; perhaps due to local heating, whereas the polythene sheet lagged behind, requiring an additional 25% time for drying.

The construction of iron sheet trays is relatively expensive requiring approximately KES 100 to be invested for every kilogram of output. In comparison the use of polythene sheet would require a fraction of this investment KES 27.

It is apparent that factoring space for drying is a critical of planning of a production site. For example, if production was 500kg / day the space requirement translates to roughly 100m2 – in an urban centre this might be prohibitive.

Also, the length of drying (3-4 days or even more in bad weather) might be problematic. Some clients could place an order requiring fuel the same day or next day and defeating even the most careful management of stock! Together with the issue of space, this points to an area for further research; development of drying equipment that reduces duration to hours rather than days.

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3.2 Business Feasibility Assessment - Assess the economic feasibility of investing in small-scale briquette production

Finally, the preceding results and analysis are brought together into 4 key business models. These are first developed and then assessed in terms of input requirements, cost of production and return on investment.

3.2.1 Model Development

Table 11 outlines the scenarios for which business models were developed.

Table 11: Business Model Scenarios

	A	**B**	**C**	**D**
Type of Briquette	Carbonised	Carbonised	Non-Carbonised	Carbonised
Feedstock	Wood Shavings	Charcoal Fines	Fine Sawdust	Wood Shavings
Binder	Clay	Clay	Cassava Starch	Clay
Briquetting Machine	Electrical Extruder	Electrical Extruder	Electrical Extruder	Manual Extruder
Carbonisation Kiln	10 x Open Carboniser	None	None	Open Carboniser
Drying Method	Iron Sheet Rack	Iron Sheet Rack	Iron Sheet Rack	Polythene Sheet

Both non-carbonised and carbonised briquette production is modelled since the comparative fuel performance tests showed that it was possible to generate both carbonised and non-carbonised briquettes that could be competitive with conventional fuels.

The feedstock study showed that a range of feedstocks could be used for making carbonised briquettes; looking at the fuel performance results, in conjunction with the carbonisation tests, wood shavings was chosen since it burned effectively and could be made by the relatively high capacity open-carboniser. Charcoal fines was also chosen for comparison, since they are commonly used by producers. Finally, fine sawdust was chosen as the best non-carbonised feedstock since it required no additional processing.

The binder assessment showed that a range of binding agents could be used for carbonised briquettes; clay was chosen as the least expensive. Only cassava starch was found to be effective for non-carbonised briquette making.

The equipment study showed that the electrical extruder was the most effective machine and was chosen for all except one scenario; which deliberately assessed lower capital options. The iron sheet rack was found to be the most effective drying method; this was chosen for each scenario except for D that went for the lower-capital polythene sheet.

3.2.1.1 Input Requirements

Table 12 shows the input requirements in terms of human resources, asset capital and working capital.

Table 12: Input Requirements for each scenario

	A	**B**	**C**	**D**
Land Area	3,800 ft^2	3,000 ft^2	3,000 ft^2	480 ft^2
Human Resources	General Manager Production Supervisor 7 x Casual Worker	General Manager Production Supervisor 5 x Casual Worker	General Manager Production Supervisor 5 x Casual Worker	Manager 3 x Casual Worker
Asset Capital (KES)	318,000	175,000	175,000	37,500
Working Capital (KES)	156,000	130,000	242,000	25,500
Total (KES)	**474,000**	**305,000**	**417,000**	**65,000**

3.2.1.2 Production Cost & Viability

Table 12 shows input requirements for various scenarios; production level, fixed costs, fixed costs and loan repayment per unit, variable costs and total cost per unit.

Table 12: Input Requirements for each scenario

	A	B	C	D
Production Level (kg / day)	800	800	800	80
Fixed Costs (KES / month)	53,600	52,600	52,600	13,300
Loan Repayment (KES / month)	17,300	11,000	15,000	2,400
Fixed Cost & Loan Repayment per unit (KES / kg)	4.54	4.08	4.34	5.00
Variable Costs per unit (KES / kg)	6.57	4.99	12.08	7.28
Total Cost per Unit (KES / kg)	**11.10**	**9.07**	**16.42**	**12.28**
Viable?	YES	YES	NO	YES

3.2.1.3 Return on Investment

Table 13 gives return on investment based on sales prices, monthly profits, internal rate of return and net present value. The Internal Rate of Return (IRR) was 100% and 68% for scenario B and A respectively while its Net Present Value (NPV) was Kshs 492,000.00 compared favorably with that for scenario A which was Kshs 420,000.00. The variation in IRR could be attributed to the type of feedstock used.

Table 13: Return on Investment for each scenario

	A	B	C	D
Sales Price (KES / kg)	15.0	12.5	N/A	15.0
Monthly Profit (KES)	61,000	54,000	N/A	20,000
IRR over 2 years	68%	100%	N/A	76%
NPV over 2 years (KES)	420,000	492,000	N/A	66,400

4. CONCLUSIONS

The economic viability of briquetting technology is dependent on a variety of factors, namely

- The type of equipment used for drying and processing materials
- The type of biomass used and their physico-chemical and thermal properties
- Skills of human resource both at technical and business level
- Investment capital

REFERENCES

[1] Akowuah, J. O., Kemausuor, F., & Mitchual, S. J. (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. *International Journal of Energy and Environmental Engineering*. doi:10.1186/2251-6832-3-20
[2] Bureau of Standards (2000). Wood Charcoal and Charcoal Briquettes for Household use. South African Standard Specification. Edition 2.2; 2002. South African Bureau of Standards. South Africa
[3] Government of Kenya (2002). Ministry of Energy. Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments. Kamfor Company Limited, Nairobi. Chapter 1, ppxiii-xviii
[4] Hu, J., Lei, T., Wang, Z., Yan, X., Shi, X., Li, Z., … 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.
[5] J.M. Onchieku, B.N. Chikamai and M.S. Rao . Optimum Parameters for the Formulation of Charcoal Briquettes Using Bagasse and Clay as Binder. *European Journal of Sustainable Development* (2012), **1**, 3, 477-492 ISSN: 2239-5938
[6] Leibbrandt, N. H., Knoetze, J. H., & Geargens, J. F. (2011). Comparing biological and thermochemical processing of sugarcane bagasse: An energy balance perspective. *Biomass and Bioenergy*, *35*, 2117–2126.
[7] Massaquoi, J.G.M. (1990). Agricultural Residues as Energy Sources, In: Baghavan, M.R. and S. Kerekezi (eds), Energy for Rural Development; Proceedings of the United Nations Group of Experts on the Role of New and Renewable Sources of Energy in Intergrated Rural Development. United Nation, Stockholm, Sweden 22-26 January 1990. Zed Books Ltd. London. Chapter 6, pp76-85

[8] Mwichabe, S. (1999). Environmental Problems in Kenya: Surviving a Spoiled Environment. Konrad Occasional Papers, East Africa. Konrad Adenauer Foundation. Nairobi, Kenya. Chapter 5, pp32-38

[9] Onchieku, J.M., B.N. Chikamai and M.S. Rao **(2012).** Development of Mathematical Models for Estimation of the Quantity of Biomass Residues. *International Journal of Applied Sciences and Technology (2012),* **Vol. 2, No. 8**

[10] Rabah, K. V. O. (2000). Sugarcane Residues as Biofuel for Cogeneration of Electricity in Kenya. In *World Renewable Energy Congress VI* (pp. 1340–1343).

[11] Singh, S. P., Asthana, R. K., & Singh, A. P. (2007). Prospects of sugarcane milling waste utilization for hydrogen production in India. *Energy Policy*, *35*, 4164–4168.

[12] Suhartini, S., Hidayat, N., & Wijaya, S. (2011). Physical properties characterization of fuel briquette made from spent bleaching earth. *Biomass and Bioenergy*, *35*, 4209–4214.