



Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies, Energy Centre

Comparative Analysis of Briquetting Most Viable Biomass Waste to Substitute Charcoal in Ethiopia

By

Anteneh Belay

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Advisor:

Dr.-Ing. Demiss Alemu

Department of Mechanical Engineering
Addis Ababa University

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Graduate Program in Energy Technology

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Anteneh Belay

Approval by Board of Examiners

Chairman Department of Graduate
Committee

Signature

Dr.-Ing. Demiss Alemu

Advisor

Signature

Dr.-Ing. Abebayehu Assefa

Internal Examiner

Signature

Dr. Tesfye Dama

External Examiner

Signature

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Least of Abbreviation

AR	Agricultural residue
JPC	Jatropha Press Cake
DOE	Design of Experiment
RSM: -	Response surface methods
BBD: -	Box-Behnken Design
DF	Desirability Function
EREDPC	Ethiopian Rural Energy Development and Promotion Center
USD	USA currency in dollar
ETB	Ethiopia currency in Birr
E.C	Ethiopian Calendar
ASTM	American Standard Test Method
ESA	Ethiopian Statistics Agency
PMC	Percentage Moisture Content
PVM	Percentage Volatile Matter
PAC	Percentage Ash Content
PFC	Percentage Fixed Carbon
WBT	Water Boiling Test
CDM	Clean Development Mechanism
DOE	Design of Experiments
% w/w	Dry Weight per Dry Weight
Kcal/kg	kilo calorie per kilo gram
P	Pressure
D	Dwell Time
BR	Binder Ratio
C.V	Coefficient of Variation
ANOVA	Analyses of variance
PP bags	Plastic Bag
KWh	Kilo Watt per Hour
m ³	Meter Cubic

Kg/hr	Kilo Gram per Hours
IRR	Internal Rate of Return
NPV	Net Present Value
GXSI	Global exchange for Social investment
T/ha	Tons per Hectare
Kg/cm ² :-	Kilo Gram per Centimeter Cubic
μm	Micro Meter
MPa	Mega Pascal
FAO	Food and Agricultural Organization
SNNP	South Nation and Nationality Peoples
ASTM D3173	Standard procedure for moisture content determination
ASTM (D3174)	Standard procedure for ash content determination
ASTM (D3175)	Standard procedure for volatile substance content determination
ASTM (D3172)	Standard procedure for fixed carbon content
ASTM(D1989)	Standard procedure for calorific value determination

Abstract

Agricultural residues seem to be the most promising energy resources for developing countries. However, the majority of them have low energy density. One of the favorable technologies for enhancing that property is charcoal Briquetting. A large amount of agricultural and solid wastes are left in the field after harvest. The primary objective of the study was to investigate the comparative analysis of resource availability, physico-chemical properties and performance of biomass charcoal produce from the most promising wastes. Specific objective were to develop and characterizing composite charcoal briquettes, investigate factors affecting densification of composite charcoal briquettes and compare resources availability, physic-chemical property and performance of charcoal briquettes with wood charcoal.

The composite charcoal briquettes were produced using ASTM standard by a combination of process factors. The three process factors were dwell time, clay binder ratio and pressure. Design expert software, Box-Henken model were employed to investigate the effect of process factors. The Density was found in the range of 783.00-1,187.00 kg/m³. The coefficient of multiple determinations for prediction of the proposed density model was about 95.7%. The effect of the three variables against density was investigated. When every two combinations of the above variables were increased, density of briquettes was also found to increase. Optimum point of dwell time, pressure and clay binder concentration was found at 3.6 minute, 45 bars and 18.27% respectively. The optimal point was validated.

The Production of 1300 tones/yr briquettes plant was evaluated. The total investment cost was found to be 1.9137milloion birr. The net present value and the internal rate of return of the project were 2,753,976 Birr and 19% respectively it implies the project was feasible.

Base on the resource estimation using production to residue ratio, the quantity of available agricultural residue, cotton stalk, coffee husk, bamboo residue and jatropha press cake in Ethiopia was approximately 4,655.887, 219.933, 109.757, 109.757,1,000 and 0.228Ktones/yr respectively. When the fixed carbon of charcoal made from bamboo, cotton stalk, coffee residue and composite with that of Acacia charcoal, 60.85, 58.4, 63.9, 68.25 and 69.74w/w % were found respectively. The above value all had relatively similar which makes it possible to substitute wood charcoal. Regarding heating values of briquettes produced from bamboo, cotton

stalk, coffee residue, composite and Acacia spp. charcoal were 29135.94KJ/Kg, 19209.03KJ/Kg, 11710.48KJ/Kg , 23446.08KJ/Kg and 32573.304 KJ/Kg respectively. But all the heat values of briquettes were lower than that of charcoal. If the country substitutes wood charcoal by charcoal briquettes, it will reduce 47.06 CH₄ / year and 1530.383 Co₂/year for every production of 1300 tons per year. The study showed that charcoal from bamboo; cotton stalk, coffee residue and agricultural residue could be used as substitutes for Acacia charcoal as they had comparable potential energy. But jatropha press cake currently had a low possibility to be use in our scenario.

Generally, this research concludes that the biomass charcoal had positive value of production method, fixed carbon and performance, but one negative value was obtained from calorific value. With $\frac{3}{4}$ positive values, these biomass wastes can substitute wood charcoal in Ethiopia.

Chapter One

1.1 Background of the Study

Any Organic material used for fuel is called biomass energy like firewood, forest wastes, dung/manure, agriculture residues and vegetable matter [1]. Energy from biomass accounts for 15% of the global energy consumption. Yet, in Ethiopia, it supplies more than 96.14% of the country's energy needs. In Ethiopia, most household applications like cooking, baking and lighting activities are based on the use of biomass. Charcoal, woody biomass, leaves, agricultural residues and animal manure are the most common forms [2]. Biomass has historically been a cheap and accessible source of fuel for Ethiopian population, but this is unlikely to continue as a high dependency results in depletion of resources as human populations and competing demands increase.

Energy Sources Used for Cooking in Ethiopia

In Ethiopia, 17% of the populations have access to electricity [3]. More than 90% of the country's total energy needs in Ethiopia comes from biomass. Of this, wood accounts for 84.98%, charcoal 3.91%, leaves/residue 2.03%, manure/dung 5.14%, saw dust 0.07% butane gas/kerosene 1.43, electricity 1.32% and others 1.11% [4].

The 2010/11 Household Survey conducted by the Ethiopian Statistics Agency provided a more detailed analysis, reporting that 87.08% of households use firewood for cooking while 3.91% use charcoal. Firewood was most commonly used by rural households, while charcoal is commonly used in urban areas. In Addis Ababa, % of the population use charcoal as their main source of fuel for cooking.

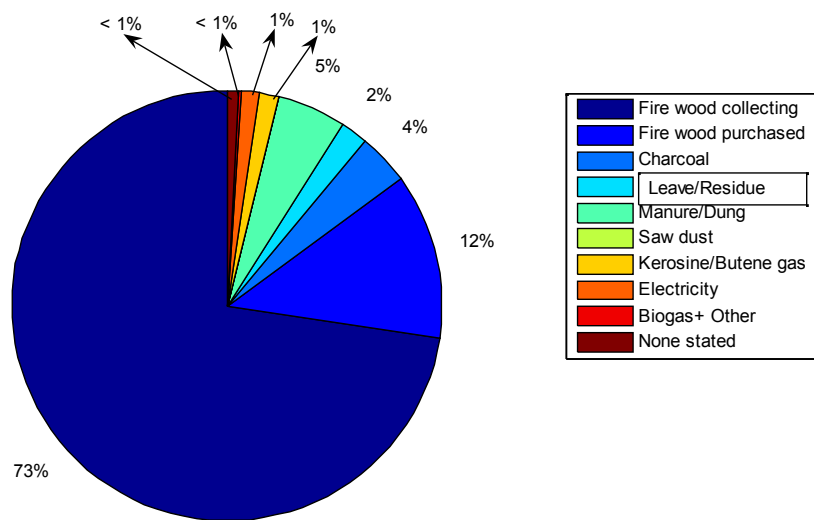


Figure 1-1: Distribution of households' energy consumption for cooking in Ethiopia:

[Source: 2011 welfare survey]

Distribution of Cooking Fuel in Rural Ethiopia Ethiopian people in rural area used to collect wood as a main source of energy for cooking. In Ethiopia there are 5000 rural villages. According to welfare survey 2011 report that the main energy sources for household energy were collected firewood and purchased fire wood and dung/ manure. As seen from the figure below 87.23% of the households used to collect firewood 3.67% used to purchase firewood. As seen from the data many households in rural Ethiopia used collected firewood, it cost time to for collecting this wood. Small household used purchased fire wood. Household used dung/Manure were 6.06%.Unlikely in rural Ethiopia no household used electricity and charcoal.

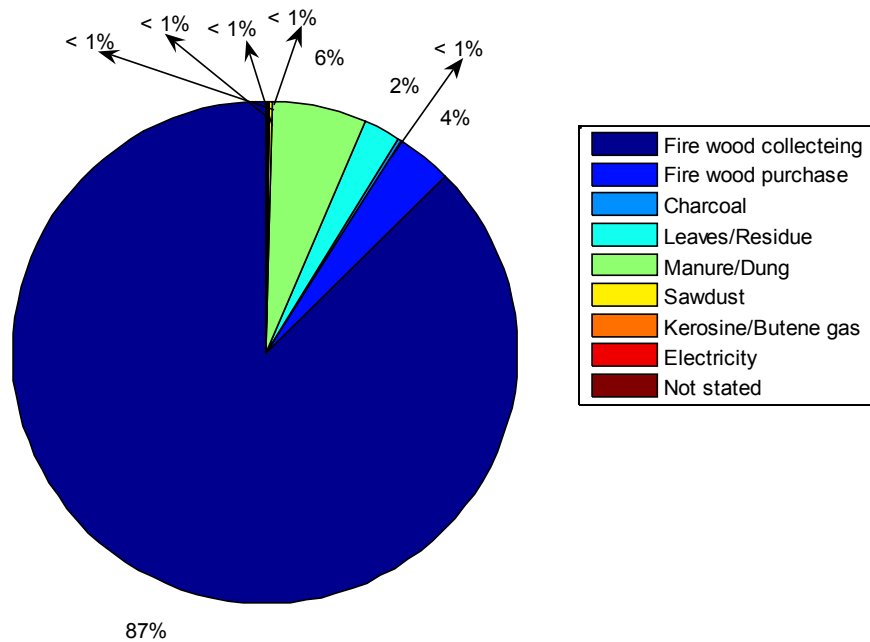


Figure 1-2: Distribution of household energy consumption for cooking in rural Ethiopia
 [Source: 2011 welfare survey]

Distribution of Cooking Fuel in urban Ethiopia The energy distribution for cooking food is urban areas of Ethiopia where wood charcoal, purchased fire wood and collected firewood. According to Ethiopian welfare survey 2011 report. 45 % of Household used purchased firewood for cooking where as 17% used charcoal and 19 of the collected firewood. There found difference in item and distribution of using energy for cooking between the urban and rural areas of Ethiopia. Urban areas in Ethiopia used charcoal and purchased firewood for cooking that makes differ from rural areas of the country. See more from the following figure.

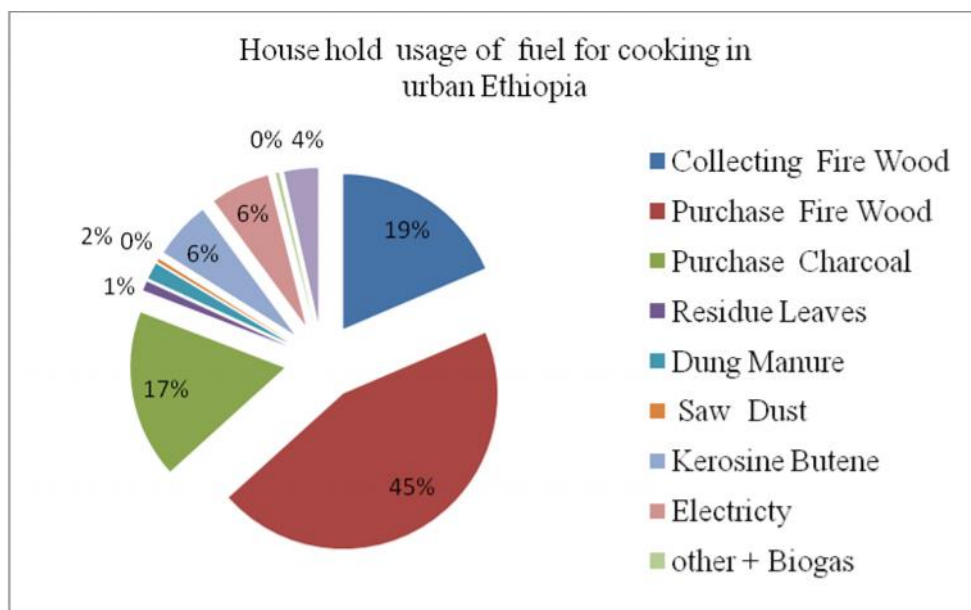


Figure 1-3: Distribution of household energy for cooking currently using in urban Ethiopia:
[Source: 2011G.C welfare survey]

Charcoal consumption in Ethiopia: The 1998, 2000, 2004 and 2011 welfare survey data showed that the number of households who used charcoal increased steadily as the population also increased. The number of household who used charcoal for cooking in 1998 was 85,261 while it turned to six digits (142,878) according to the 2000 welfare survey. After four years (2004) the number of households became 180,260. In 2011, the charcoal consumption has shown a fourfold increase (631,447).

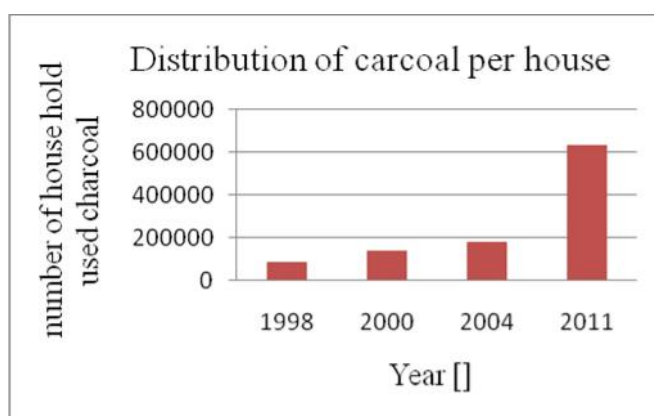


Figure 1-4: The number of household used charcoal for cooking from 1998-2011GC [Source: CSA]

The main energy source for urban areas in Ethiopia is wood charcoal. Charcoal is mainly produced in rift valley areas, central part of the country and afar region. These are the highly populated parts of the country and where large urban centers like Addis Ababa are located. Southern Nations Nationality and Peoples (SNNP), Afar and Oromiya are the regions which feed charcoal to the central high charcoal consumption place (Addis Ababa). A survey carried out in June 2000 at the four main entry roads to Addis Ababa indicated the weekly volume of charcoal supply in the city from the four directions (Table 1.1).

Table 1-1: The weekly volume of charcoal supply to Addis Ababa at the major entry roads (June 2000)

Road Entry Point	Charcoal Volume (Sacks/Week)	
	Sack/Week	% Total
Debrezeyit	1610	37.03
Dessie	1386	31.88
Jimma	722	16.61
Wollega	630	14.49
Total	4348	100

Source: FDRE Ministry of water and energy

Charcoal production/supply areas are reported to be located within the boundaries of Addis Ababa (10 Km) to locations situated as far as 300 Km (Afar region) or even more. In every road to Addis, charcoal market is available. The biggest charcoal market was found between Awash Meleka and the State cotton farm at Awash Basin, along the road (Addis-Assab). More than 20 Charcoalers are selling charcoal at one place, each having about 10 sacks. Trucks moving on the road, mainly in the direction to Addis, stop-by and carry a maximum of two sacks. The checkpoint at Awash could only allow one charcoal sack per passenger [5]. Wood Supply for charcoal manufacturing. The most common tree species for manufacturing charcoal are Acacia trees. And in some areas, species like Eucalyptus are used. In Ethiopia, charcoal from Acacia wood had good fuel characteristics like high density, low ash content, high strength and heating value. Different tree species are used for charcoal manufacturing throughout the country. See table 1.2 below.

Table 1-2: Tree species used for making charcoal in Ethiopia

Town	Region	Tree Species
Nazeret	Oromiya	Tedicha(acacia), kontir
Wollenchite	>>	Tedicha
Alem Tena	>>	Tedicha
Meki	>>	Dodoti,Tedicha
Ziway	>>	Dodoti,Tedicha
Mojo	>>	Dodoti,Girar(acacia)
Guder	>>	Girar,Arengma,Maiasa
Ambo	>>	Girar,Arengma,Maiasa
Shashemenne	>>	Dodoti.Girar,Bedeno
Bahirdar	Amhara	Abalo,Tigi
Fenote selam	>>	Mixture of Sesa,Shekeshek,and wanbilo
Deber Markos	>>	Moke,Grar
Dejen	>>	Moke,Grar
Goha Tsiyon	Oromia	Shefer,Dare,Grare
Fichae	Oromia	Shefer,Dare
Dessie(SegonGebeya)	Amhara	Grare,Sholla
Dessie(Center)	Amhara	seban,grare
Awash	Afar	Accaica Nilotica(Girar),Prosopis
Deber Birhan	Amhara	Basana,Grare

Source: FDRE water and energy minister [report study of 2008]

The forest resources of Ethiopia are mainly concentrated in the Southern and Southwestern parts of the country (Table 1.2). The North and central parts (densely populated) have a very small area of indigenous forest. The Woody Biomass Inventory and Strategic Planning Project (WBISPP, 1995) reported that even in the relatively high forested parts of the country, (Southern and Southwestern) the forest resources are exploited in an unsustainable way. According to this study, by 2015 the woody resources available in this part of the country will decline to about half from the stock level in 1995(630.71).

Table 1-3: Standing stock in southern and western Ethiopia and its rate of depletion

Locality	Stock in 1955 (million tones air dry)	Consumption (% of yield)	Stock Remaining By 2015	
			million tones	% of 1955
Arsi	22.26	26.2	6.89	31
Bale	40.58	126	28.5	70
Gamo-gofa	59.5	92	34.07	57
IIIubabour	155.13	37	116.32	75
Kefa	138.39	106	53.38	39
Shewa	31.15	78.8	1.24	4
Sidamo	141.5	90	103.39	73
Welega	42.2	178	0.22	1
Total	630.71		244.01	55

Source: FDRE Water and Energy Minister

Charcoal Making Process in Ethiopia The main technology used for making charcoal in Ethiopia is Earth Mold Kiln. The efficiency of this method is very low (8 to 12%) with a capacity of 4 to 7 cubic meters of wood [5].Charcoal making is an illegal activity in the country. Farmers are able to produce a small amount of charcoal unnoticed (illegally). However, an exception is in the Afar region where the Charcoalers use wood from land reclamation operations and stack large volume of earth mound kilns. Kilns production capacity ranges from 70 to 120 sacks. Kiln production cycle (wood cutting, collection, kiln stacking, carbonization, cooling and product packaging into sacks) often takes more than a month. Charcoalers are organized in groups, 6 to 12 persons each. The kilns are individually owned, but the groups co-operate in wood transport, kiln stacking, carbonization supervision and packaging.

Charcoal Producers and Production levels

In Ethiopia, there are no professional charcoal producers. Most Ethiopian farmers make charcoal for generating income during off-season. On average, they produce 100kg of charcoal using a single kiln. Assuming that they produce 12 times a year on part-time basis, they will have 1200 kg of charcoal per year. If we assume 300,000 tone of charcoal is consumed each year throughout the country, 250,000 people will be involved out of 87,000,000 populations.

Charcoal Trade and Traders

Charcoal trading is not an organized business in Ethiopia. However, there exist relatively small wholesale depots (around 200 to 300 sacks) and retail outlets (10 to 50 sacks) in the urban areas like Addis Ababa. Several retailers, about 10, are usually present in one area. The wholesale depots and retail outlets are well distributed all over the city close to the consumers (mainly households). The charcoal arrives to cities and towns in small batches, mainly transported by donkeys, camels and trucks. Trucks passing the checkpoints are not allowed to carry more than one sack per passenger. Both wholesalers and retailers have direct access to suppliers.

1.2 Statement of the Problem

Agricultural residues seem to be the most promising energy resources in Ethiopia. However, the majority of them have low energy density. One of the favorable technologies for enhancing that property is charcoal Briquetting. Jatropha press cake, agricultural residue, bamboo, coffee stalk and cotton stalk where the most important biomass wastes in Ethiopia. Therefore, a large amount of this is left or burnt in the field after harvest. This study was aimed at investigating the comparative study of the above biomass charcoals based on the three perspectives, namely availability of the resource, physic-chemical property and performance. Comparative study of coffee residue, cotton stalk, bamboo and composite (Jatropha press cake and agricultural residue) charcoal briquettes were not done before in Ethiopia.

1.3 Objectives

1.3.1 General Objective

The overall aim of this work was the comparative study of charcoal Briquetting based on resource assessment, physic-chemical property and performance with wood charcoal in Ethiopia.

1.3.2 Specific Objectives

The specific objectives of the study includes:-

- i. develop and characterize composite charcoal briquettes
- ii. Investigate factors affecting densification of composite charcoal briquettes.

- iii. Compare resources availability, physic-chemical property and performance of charcoal briquettes with wood charcoal.

1.4 Significant of the Study

This comparative study helps policy maker and environmental activists to know the best briquettes. The finding of this research can help new entrepreneurs develop new product using this waste. The finding could serve to prepare a database of national biomass fuels, supporting decision making on energy conversion and implementation.

1.5 Scope of the Study

In this research, only four biomass materials were evaluated to substitute wood charcoal in Ethiopia. The biomasses investigated here were bamboo residue, coffee pulp, cotton stalk, agricultural residue, and jatropha press cake. The scope of the study was seen with respect to:-

1.5.1 Geography

The study covered the total areas of Ethiopia. The country administrative areas were used to assess the availability of the resource.

1.5.2 Context

Physico-chemical properties of charcoal briquettes from cotton stalk, bamboo and coffee residue were done in EREDPC Laboratory and these characteristics were used for the investigation. But, availability, physic-chemical and performance of composite (Jatropha press cake and agricultural residue) charcoal briquettes were not done before. The research focused on assessing comparative study on resource availability, physic-chemical property and performance evaluation charcoal briquettes to substitute wood charcoal in Ethiopia. The Physico-chemical properties of three biomass briquettes: - coffee pulp, cotton stalk and bamboo had been investigated in Ethiopia by Ethiopian Ministry of water and energy. But Composite charcoal briquettes of agricultural residue and Jatropha press cake were produced in this research. Physico-chemical and performance evaluation of composite charcoal briquettes were also measured.

1.6 Limitation of the Research

Assessment of Market availability, socio-economic impact of using briquettes and comparison of production cost using charcoal briquettes was not done in this research. Data from the national statistical agency was used in the study.

1.7 Thesis Organization

Chapter 1: Introduction Chapter 2: Literature review Chapter 3: Methodology of the study
Chapter 4: Analysis for Composite Charcoal Briquettes Chapter 5: cost of composite briquettes
production Chapter 6: comparing biomass briquettes with charcoal Chapter 7: conclusion and
recommendation Chapter 8: Reference

2 Chapter Two

Literature Review

2.1 Charcoal Briquettes Production Method

Briquetting process has many processes like carbonization, screening, Mixing/densification and drying. See the following Table 2.1 for more clarification



Figure 2-1: Flow diagram for manufacturing Briquettes

If the feedstock's moisture content $>15\%$, it is dried before carbonizing. Milling process will be relevant if the feedstock has high particle size. Screening helps to separate the particle. Depending on the material, the pressure and the speed of compaction, additional binders, such as starch or clay soil may also be needed. Briquetting production can be modeled in three: - family, community and industrial level. Although a variety of types and scales of machines and equipment can be used, the main processing steps remain the same. These are described below. Carbonization (or partial pyrolysis) drives off volatile compounds and moistures leaving a fuel with a higher proportion of carbon remaining (char). This same process creates charcoal from wood and is preferred, particularly in urban environments for its superior burning characteristics and smokeless use. Conversion to char in a controlled process also reduces the amount of harmful emissions compared to burning of raw biomass. The decision to carbonize depends on the application.

Methods of carbonization in Ethiopia largely follow traditional charcoal making techniques, which achieve conversion efficiencies of 10-15% [5]. However, some improved processes have been developed for small scale charcoal production, with improved efficiencies of up 40% [5]. Screening Before compacting into a briquette, the feedstock must be in a powder form to have uniform size. Some raw materials such as sawdust and rice husks are already in small particle form, however others, such as baggasse, straw and large charcoal fines need powdering.

Grinding can be done manually by crushing, chopping or by using mechanized milling machines. It is often then sieved (screened) to ensure consistency in the powder. Binding is the process of ‘sticking the compacted material together’. If subjected to a sufficiently high temperature and pressure, biomass materials can bind together naturally, without the addition of extra binding agents. Pressure $< 5\text{MPa}$ needs a binder, pressure $> 5\text{Mpa}$ doesn't need a binder [6]. High temperature can melt a naturally occurring substance called lignin and under pressure this can act as glue. If high temperatures cannot be achieved, (because almost all briquettes machines are manufactured locally) additional binding agents need to be added to enhance or activate the binding process. Common binders include: -molasses, fine clay, cassava flour, red soil and wheat flour. Drying Raw materials need to be dried prior to Carbonization. For the briquettes being effective in burning, they have to be dried in less than 10% moisture content. The most common method for doing this in Ethiopia is through sun-drying. This is usually done by laying the briquettes out on polythene or iron sheets or a wire mesh. Sun-drying can take up to 3-4 days to dry the briquettes completely. The largest producer of non-carbonized briquets in Ethiopia uses Flash Drier in addition to sun-drying. Briquetting/Densification Worldwide a number of machines and techniques have been developed for Briquetting on a range of different scales. The leading types are described here. Piston Extruders are relatively large machines in which a heavy piston forces biomass material through a tapered die. These are capable of producing non-carbonized briquettes:

- Biomass is forced through a tapered die by a ram using high pressure
- Briquettes are extruded as a continuous cylinder.
- The area of the die tends to determine the output of a machine; the larger die (and correspondingly larger machine components) results in a larger production rate.
- Flywheel drive machines can produce between 250-750kg of briquettes per hour while hydraulic machines typically produce up to 200kg per hour Screw Extruders use a screw action to extrude a briquette through a die.

Biomass is fed into the machine from a hopper into the screw chamber. Powered by an electric motor, the screw forces the material through a die and out of the machine as a continuous (usually cylindrical) briquette.

A Conical Die Screw Extruder uses a conical screw that tapers from large (at the input) to small (at the output). This type of machine can achieve high pressures, generating sufficient compaction for Briquetting both carbonized and un-carbonized feedstock.

A Heated Die Screw Extruder uses a non-tapered screw and a heated die that enables lignin breakdown to occur, making it suitable for Briquetting un-carbonized feedstock.

Plain Screw Extruders are the most common type used in East Africa due to the simplicity of the mechanism and can be fabricated by skilled workers using locally available tools.

They can often be adapted from similar devices such as a meat mincer, however are only suited to making carbonized briquettes. Roller Presses are commonly used to make charcoal briquettes. They involve two adjacent counter-rotating rollers with indentations in the shape of the desired briquette. Powder is fed from above, which falls into the indentation and is compressed as the rollers turn. The briquette then exits the machine as a single pillow shaped lump. The level of compaction achieved by a roller press is relatively low compared to a piston or screw extruder and so is suited more to Briquetting of wet powders containing a binding agent. However the production rate of a roller press can be very high, reaching 1.5 tones per hour.

Roller Presses are used by most of the largest East African producers of carbonized briquettes. A considerable number of low-capital manual techniques have been developed both for carbonized and non-carbonized feedstock. Many of these designs have been disseminated in developing countries to encourage the production of briquettes among rural communities who would otherwise lack access to industrial technology.

2.2 Numerical Literature

2.2.1 Biomass Briquetting and Experimental Design Method

Many researchers develop new charcoal briquettes for testing the physico-chemical and performance properties. These researchers used different methods of data analysis. Briquetting process depends on properties like process variables (temperature, pressure, retention or hold time and relaxation time, die geometry and speed), raw material variables (moisture content, particle size, shape, distribution, binder type and ratio [7]). One or combinations of the above factors have a significant effect on physicochemical property. For manufacturing the best

briquettes the one or more combination of property were used. To compare biomass made from different materials, the best factor should be chosen. The best way to determine the optimal point of the above property was by combining the factors using design expert software. Y Song et al. [8]; four biomass samples were densified using laboratory hydraulic press Briquetting machine under three pressure levels (7.5, 10, 12.5 MPa), three levels of temperature (90, 110, 130°C), at three moisture content levels (9, 12, 15% w.b), and three levels of particle size (19.1, 25.04, 31.75 mm) at dwell time about 30 s. the response variables were density, durability, dimensional stability, and moisture content. The experiments were done using box-henken method. Youndrie et al work [9]; used pressure (3,000,5,000 & 7,000 psi) ,particle size (20,40,60) and moisture content(5,10,15) as independent variables. Youndrie employed Box-Behnken design experimental method and used relaxation density and durability as the response variables. Then, he found the optimal point at pressure of 3002.8psi, the particle size 34.9 meshes and raw material water content of 7.79% which gave maximum density of 1.0 g/cm³.

2.2.2 Comparative Study Based on Biomass Resources

Bruna Missagia [10] investigated Comparative Analysis of Brazilian Residual Biomass for Pellet Production. The research was limited to compare physico-chemical properties of biomass pellet made from four types of Brazilian biomass - rice and coffee husks, sugar cane baggasse and sawdust from Eucalyptus spp. of Wood. Pellets are the best options to use for power generation and for surprise exporting to other countries.

2.2.3 Comparative Study Fuel Based on Physic-Chemical Property

Vongsaysana Sayakoummane [11] research investigates the comparison of physical and chemical characteristics of biomass charcoal with wood charcoal. This research tries to compare the physical property (gross heating value) and ultimate analyses (moisture, volatile, ash and fixed carbon content) of Six samples of wood charcoal *Cratoxylum cochinchinense*, *Pterocarpus marcocapus*, *Pinus merkusii*, *Sindora siamensis*, *Ketepeleeria davidiana* and *Pettophorum dasylochis* and saw dust charcoal briquette. The result shows charcoal briquettes with calorific, fixed carbon, moisture content and ash content with 7,595cal/g, 78.68%, 1.88% and 3.79% respectively. The result showed that sawdust charcoal briquettes had good quality in gross calorific value and fixed carbon. On the other hand sawdust charcoal briquettes had low moisture

and ash content of, respectively, comparing the different species of wood charcoal. The research concludes that sawdust charcoal briquettes can be used as an alternative source of fuel consumption for Khammouane province. This province is located at Lao Peoples Democratic Republic (PDR).

Dahlang Tahir [12] Physical property of biomass charcoal briquettes made from different raw material varies as the dosage of binder varies. Dahlang et. al works to prove this using four biomass type (groundnut shell, durian shell, cassava peel) with binder at a ratio of 10, 20 and 30% by weight. The Moisture, ash, volatile matter and compressive strength show proportional relationship with the amount of binding agent. For comparing charcoal from groundnut shell had the highest calorific value, followed by durian shell and cassava peel. Rotimi Moses Davies et al [13] study investigated calorific values, ignition time, burning rate, specific fuel consumption, fuel efficiency and water boiling time of biomass briquettes. The research used briquettes of water hyacinth and plantain peel as a binder. The research compares briquettes with mangrove wood, charcoal and *Anthonotha macrophylla* (firewood). The result shows that the Thermal fuel efficiency of the briquettes produced from this densification variable competed favorably with charcoal, firewood and red mangrove wood. Furthermore, the fuel efficiency of charcoal ($31.29 \pm 0.19\%$) was the highest, followed closely by fuel briquettes ($28.17 \pm 0.88\%$). The calorific values of the energy sources ranged from 4166.67 ± 4.33 kcal/kg (firewood) to 6552.00 ± 4.73 kcal/kg (charcoal). The variation of the caloric values of the fuel types was significantly different ($P < 0.05$). The recorded boiling time values were 11.43 ± 0.43 min (briquettes), 14.94 ± 0.22 min (charcoal), 9.25 ± 0.42 min (firewood) and 8.99 ± 0.22 min (mangrove). The values of the water boiling time of the energy sources were significantly different ($P < 0.05$). There was a significant difference in a variation of the ignition time of the energy sources The variation of the burning rate values of fuel types was significantly different ($P < 0.05$). The results confirm the possibility of utilizing water hyacinth as fuel briquettes of a good source that support combustion. The water hyacinth briquettes possess higher material strength as well as high value combustible fuel, which qualify them as an alternative to firewood for domestic and industrial energy.

David K Chirchir et al. [14] Combustion characteristics like density, calorific values ignition and burning time were affected by the binder types and ratio. The research focused on evaluating the physical and combustion characteristics of rice husk-baggasse-charcoal dust composite briquettes. Rice husk and baggasse were carbonized in a muffle furnace at 450 , grounded, sieved

and mixed with charcoal dust at different mixture ratios. The mixtures were bonded with different types of binder at varying amounts before Briquetting at 5 MPa using a hydraulic press into different sizes. Physical and combustion tests were conducted according to standard procedures. The binder types and ratios had an effect on the density, calorific values, ignition and burning time that could be attributed to the incombustible matter. It was concluded that briquettes bonded by molasses binder had better combustion characteristics. There is need to study the use of other binder materials. Idah, P. et al [15], research compare energy value of briquettes made from sugar cane baggasse ,rice husk, maize cob and ground nut shell with two organic binder(banana peel and cassava peel gel). The mean bulk densities of briquettes produced from rice husk, maize cob, groundnut shell and sugar cane baggasse were 0.75g/cm³, 0.69g/cm³, 0.81g/cm³ and 0.65g/cm³, respectively. From the results obtained showed that the average energy values of the briquettes produced using cassava peel as binder and banana peel from rice husk, maize cob, groundnut shell and sugarcane baggasse were 26.612MJ/Kg, 28.255MJ/Kg, 33.703MJ/Kg and 32.762MJ/Kg, respectively. The corresponding average values for those produced using banana peel as binders were 29.980MJ/g, 28.981MJ/g, 32.432MJ/g, 31.508MJ/g for rice husk, maize cob, groundnut shell and sugarcane baggasse, respectively. The results indicate that briquettes produced from groundnut shell using cassava peel gave the highest energy value of 33.70 MJ/kg while those obtained from rice husk using cassava peel gave the lowest calorific value of 26.61MJ/kg and these were significantly different(p = 0.05). The briquette from groundnut shell is therefore more suitable for starting and maintaining a fire for cooking and other domestic heating. The briquettes from these by-products in terms of energy values are ranked as follows: groundnut shell > sugar cane baggasse > maize cob > rice husk. The effective utilization of these agricultural by-products as high grade solid fuel can reduce environmental pollution resulting from the wastes and also help in minimizing the energy crisis resulting from non- renewable energy sources like petroleum products as domestic fuel..

[16] An effort to provide an affordable firewood alternative to the rural households in Nigeria, a study was carried out to compare some properties of bio briquettes (elephant grass and spear grass) and biocoal briquettes prepared at moderate pressure, 5MPa and ambient temperature with wood samples. It was found that elephant grass and spear grass have calorific values of 15.98MJ/kg and 16.13MJ/kg, densities of 0.319g/cm³ and 0.367g/cm³, durability ratings of 92.42% and 90.54% and moisture contents of 8.00% and 7.9% respectively. Comparing these

properties with some wood samples, it was observed that there is a need to enhance the heating values and energy densities of the briquettes in order for them to compete favorably with firewood especially for industrial applications. Proximate analyses show that the elephant grass and the spear grass used to contain calorific values of 14.66MJ/kg and 15.12MJ/kg, moisture content of 9.26% and 10.13% and ash contents of 5.18% and 6.18% respectively [17]. This study sought to assess the physico-chemical properties of charcoal briquettes produced in Ghana and also establish demand for and willingness of potential users to substitute charcoal and firewood with a charcoal briquette. A laboratory experiment was conducted to determine the physico-chemical characteristics of the briquettes. This was done prior to the distribution of the briquette to potential users to collaborate their views or otherwise on the handling and burning characteristics of the charcoal briquette. A survey was undertaken a week later using questionnaires to assess the willingness of the potential users to use the briquettes. Sixty respondents were purposively selected from households and the hospitality industry for the survey. The results of the physico-chemical assessment of the briquettes were as follows: length (75 to 120 mm), moisture content (5.7% dry basis), density (1.1 g/cm³), ash content (2.6%), fixed carbon (20.7%), volatile matter (71%) and calorific value (4,820kcal/kg). Responses from the survey indicated that the briquette is easy to ignite, has a long burning time and has good heat output. Respondents also observed that the briquettes did not give off sparks and had less smoke and ash content as compared to the regular charcoal they often used. Finally, 93% of the respondents indicated their willingness to use the briquettes if the price was comparable to charcoal.

Oladeji, J. T. [18] Comparative study of briquetting made from corn cobs, groundnut shells composite mixture of the two residues. This research used the existing Briquetting machine. The maximum density, relaxed density, density ratio, relaxation ratio and compaction ratio were determined for briquettes from each residue and their mixture. The energy values of the briquettes were also determined. The initial moisture contents of corn cob and groundnut shell were 16% and 12% respectively, while the corresponding final moisture contents were 13% and 9.11%. The maximum and relaxed densities were 842.7 kg/m³ and 492.57 kg/m³ for briquettes produced from corn cob respectively, while the corresponding values of maximum density for briquettes produced from groundnut shell and their mixture were 986.8 kg/m³ and 1129.9 kg/m³ respectively. For the relaxed densities, the values 672.57 kg/m³ and 959.7 kg/m³ were obtained

from groundnut shell and the mixture respectively. The density, relaxation and compaction ratios for corn cob, groundnut shell and the mixture were respectively (0.584, 1.71, 5.44); (0.695, 1.44, 7.05) and (0.849, 1.17, 7.66). Briquettes produced from these residues would make better biomass fuels, with briquettes from their mixture having an edge over the briquettes produced from each of the residues. Savitri Garivait [19]:- Traditional energy source, especially in rural areas for decades. Various types of biomass are available mostly in the form of non plantation resources. A recent study showed that agricultural residues are the most potential considering their quantitative availability. In order to characterize the physical and chemical properties of Thai agricultural residues to be used as feedstock for energy conversion process, we developed an analytical protocol. Agricultural residues from major Thai economic crops, including paddy, maize, sugarcane and oil palm, were analyzed. In this paper, details of the analytical protocol are first described, and then preliminary results are presented and discussed in comparison with data referenced in the literature.

2.2.4 Comparing Charcoal Briquettes by Performance

T.U. Onuegbu [20] comparative study of this work is aimed at comparing the ignition time and water boiling test of coal briquette blends with pennisetum purpurem (elephant grass) and Imperata cylindrical (spear grass). Proximate analyses and elemental compositions of the coal and biomass were determined. Different samples of briquettes were produced by blending varying loads of the plant materials with the coal in the ratio of 0:100, 10:90, 20:80, 30:70, 4:60, 50:50, and 100:0, using cassava starch as a binder and calcium carbonate (Ca (OH) 2) as a desulfurizing agent. The results of the properties tested were compared. Ignition timing decrease with an increase in the plant material while coal blends with pennisetum purpurem performed better. In the water boiling test determination, burning rates as well as specific fuel consumptions were also determined. There is a variation in the results obtained. Ignition timing There was a significant difference in a variation of the ignition time of the energy sources The variation of the burning rate values of fuel types was significantly different ($P < 0.05$ [20]). Water boiling test:-The recorded boiling time values were 11.43 ± 0.43 min (briquettes), 14.94 ± 0.22 min (charcoal), 9.25 ± 0.42 min (firewood) and 8.99 ± 0.22 min (mangrove).

3 Chapter Three

Methodology of the Study

3.1 Study Area:

The area of Ethiopia is estimated to be about 1.1 million square kilometers and the current population is approximately 80 million, of which more than 84 % live in rural areas. The federal government of Ethiopia has 9 Regional states: namely Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, Southern Nations, Nationalities and Peoples (SNNPR), Gambella, Harari and two Administrative states (Addis Ababa City administration and Dire Dawa city council). The regional states as well as the two city administrative councils are further divided into eight hundred woredas and around 15,000 kebeles (5,000 Urban & 10,000 Rural)[21]



Figure 3-1: Ethiopian political map: [Source: World Map]

For the purpose of this study, biomass wastes were defined as organic residues, surpluses and by-products of agro-industrial processing. For this study, five biomass wastes were selected for comparative study. These are bamboo waste, cotton stalk, coffee residue, agricultural residue and

Jatropha press cake. The above biomass wastes were selected based on availability and less costly to use. Resource assessment, physico-chemical property and performance were the parameters used for comparing briquettes made from the aforementioned wastes. The physico-chemical property of biomass charcoal from bamboo, cotton stalk, coffee residue and two wood charcoals (acacia spp. and prosopis) had been done before. (See Fig 3.2 the general flow diagram of this research) jatropha press cake (JPC) and agricultural residue (AR) were the candidate resources in Ethiopia and no research has been conducted with briquettes of these wastes. In this research, composite charcoal briquettes were produced and comparison was made with wood charcoal and other candidate charcoal briquettes.

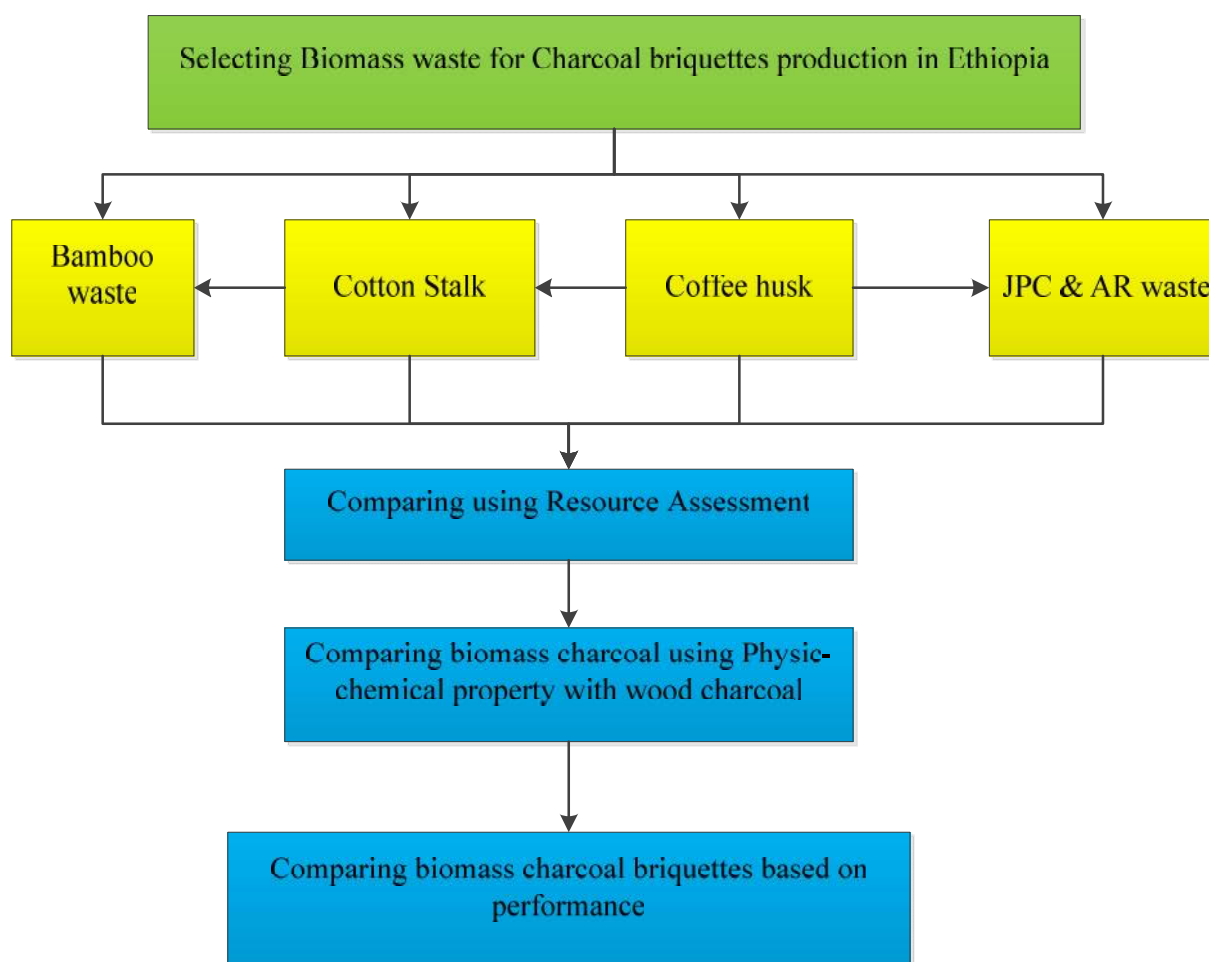


Figure 3-2: The general flow chart of the research

Composite charcoal briquettes of agricultural residue & Jatropha press cake were investigated. The Jatropha press cake (JPC) and agricultural residue (AR) were taken from rural areas near

Addis Ababa while raw jatropha were taken from Bahirdar University. This study was done in Addis Ababa University, school of Mechanical and industrial Engineering, Chemical and Bio-energy laboratory.

The research consisted of three steps:

- Developing and characterizing composite charcoal briquettes
- Investigating factors affecting densification of composite charcoal briquettes.
- Comparing resource availability, physic-chemical property and performance of charcoal briquettes with wood charcoal.

3.2 Feed Stock Preparation

In this research, composite charcoal briquettes were produced at the optimal point of pressure, dwell time and Clay binder. Physico-chemical properties (proximate and ultimate analyses), mass balance analysis, performance test and production cost were done. The flow chart method is presented in Figure 3.3.

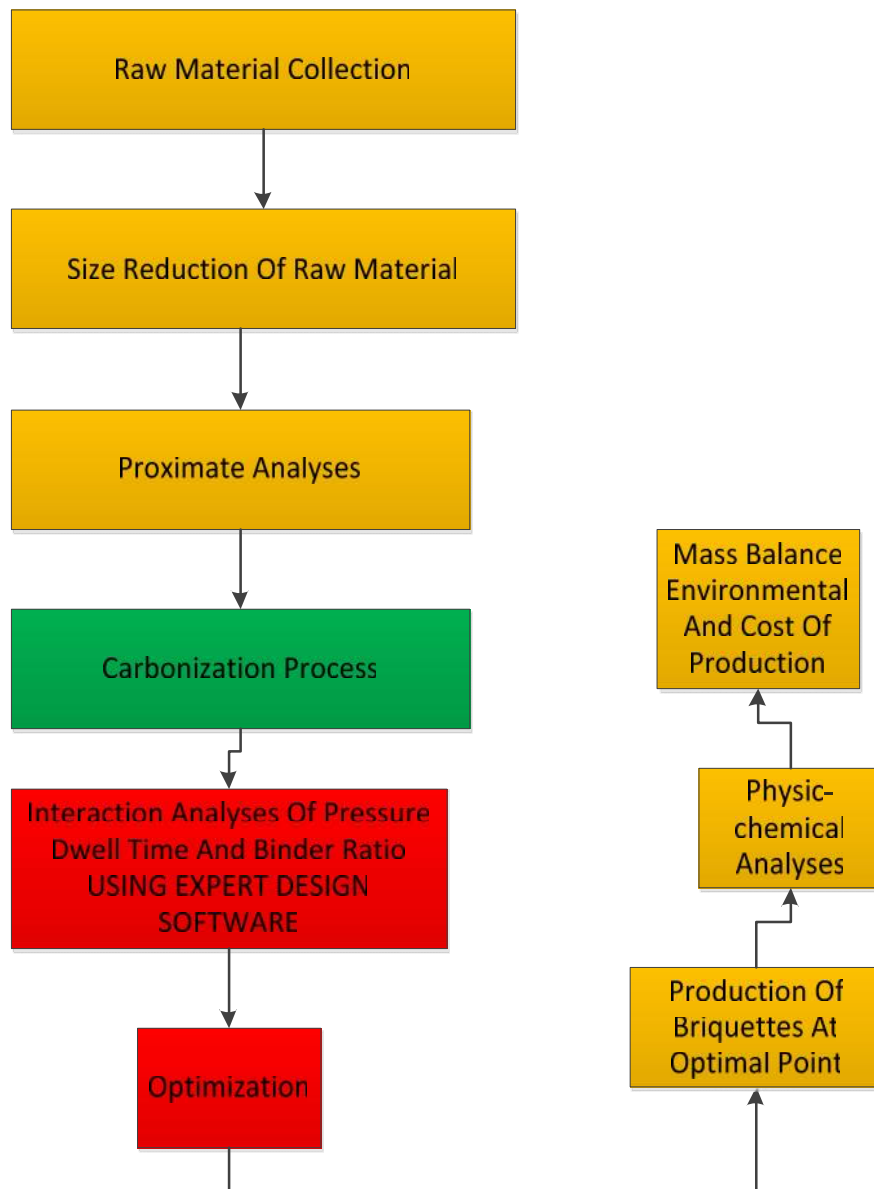


Figure 3-3: The flow chart to produce biomass charcoal briquettes

3.2.1 Sample Collection

i. Agricultural Residues (AR) Sample

The agricultural residue (AR) used for this experiment were collected from a nearby village in Addis Ababa. In this research, agricultural residue (AR) ranges from crop residue, plant wastes, grasses grain crop residue. Particularly for this study, a mixture of barley and wheat straw (both

categorized into agricultural residue) were used for densification process. 10 kg of barley and wheat straw were collected from Sendafa small village, near Addis Ababa. The village is far from Addis Ababa, around 40 km.

ii. Jatropha press Cake (JPC)

Sample For this research, the raw jatropha collected from Bahirdar University and squeezed using locally produced jatropha oil extractor in Ethiopian water and energy Minister Laboratory. The locally produced machines used in this research have an efficiency of about 17%. Due to the low efficiency of the machine, the oil in the cake was high. To remove the oil from the cake, the chemical extraction process has taken place. N-hexane was used for the removal of the oil.



Figure 3-4: Jatropha press cake after squeezed by local jatropha extraction machine

3.2.1 Sample Screening

The purpose of the screening was to separate raw material particles or charcoal powder produced by size reduction process. In this research, the materials used for making charcoal briquettes were screened twice. The first screening was performed before carbonization. In this case, the wheat and barley straws (agricultural residue) were reduced to 2-3 mm and the jatropha press cake to < 1.5mm by wood saw and small grinding machine respectively.



Figure 3-5: The jatropha press cake after the grinding and sieved by < 1mm

The second screening performed after the carbonization process. In this case, grinding machine was used to reduce particle size and sieve at $< 0.75\text{mm}$. This grinding process helps to homogenize the particles during densification [22].



Figure 3-6: Carbonized AR powder after grinding and sieved $< 0.75\mu\text{m}$

3.2.2 Carbonization Process of Samples

The carbonization process was done using muffle furnace. But for mass production, it is recommended to use locally produced carbonizing drum/kiln. This study employed 60 grams of raw material as an input and 20 gram of the char were obtained finally. The process was done frequently because of its small capacity.



Figure 3-7: Muffle furnace used for carbonized raw material

The Agricultural residue (AR) was chopped with wood saw to reduce the dimension to 2-3mm. Agricultural residue (barley and wheat straw) were carbonized using muffle furnace at for 45 minutes as recommended from [23] studied.

The Jatropha Press Cake (JPC) put in to muffle furnace. According to [24] study it was recommending high jatropha press cake char was at 400°C for 15 minute almost 30% char were got. The particle sizes of jatropha cake were < 0.5mm.

3.2.3 Ultimate and Proximate Properties Determination

Proximate analysis of raw agricultural residue (AR), jatropha press cake (JPC) and agricultural residue and jatropha press cake charcoal powders property consist of moisture content ASTM D3173, ash content ASTM (D3174), volatile substance content ASTM (D3175), fixed carbon content ASTM (D3172), calorific value (D1989) were measured. The purpose of this analysis was to know the material characteristics before used to produce briquettes [25].

3.2.4 Densifications of Biomass and Design Expert Software

Densification affected by many process variables (pressure, temperature, die geometry and die length) and feed stock material property (moisture content, binder type and ratio) [26]. Variation on the above parameter made a significant change on the quality of briquettes. To have the best briquettes quality the variable will set at optimal. Improve the quality of briquettes manufacturing using simple mechanical pressing technology first determine the optimal point of pressure, dwell time and clay binder concentration. The best way to vary these three parameters at three levels was use design expert software.

Design-Expert software was used for designing experiments (DOE). This software is a Windows based program to optimize your product or process. It provides many powerful statistical tools [28]. Some features from the software

Two-level factorial screening designs: Identify the vital factors that affect your process or product so you can make a breakthrough improvement,

General factorial studies: Discover the best combination of categorical factors, such as source versus type of raw material supply,

Response surface methods (RSM): Find the optimal process settings to achieve peak performance.

Mixture design techniques: Discover the ideal recipe for your product formulation, Combinations of process factors, mixture components and categorical factors: Mix your cake (with different ingredients) and bake it too!

3.2.5 Response Surface Methods (RSM)

RSM is a collection of mathematical and statistical techniques that are useful for modeling and analysis in applications where a response of interest is influenced by several variables and the objective is to optimize the response by minimization the experimental runs [28]. In this research, we have three variables varies in three levels. Among the variables the first one was pressure, which varies with three levels 40 bars, 60 bars and 80 bar because of the briquette machines introduce in Ethiopia were local manufactured at low pressure (mechanical densification). The second variable had been dwell time the dwell time for low pressure briquettes varies from 5-15 minute, according to [29] work and in this research the dwell time were varies from 3 ,5 and 7 minute. And the third variable was binder ratio since in Ethiopia all local briquettes manufacturing enterprise use clay as the binder at a ratio of 20%. In this research clay concentration varies from 10, 20 and 30%. The response was density. The best models to solve our problem were RSM optimization options using Box-Behnken “BBD” design Method.

3.2.6 Box-Henken Model

Box-Behnken experimental design, which is a three level design based on the combination of a two level factorial design and incomplete block design. It is useful for statistical modeling and optimization of a response variable of interest, which is a function of three more independent variables. Moreover, Box-Behnken designs allow estimating coefficients in a second degree polynomial regression and modeling of a quadratic response surface. The response surface can be further used for process optimization, identification of maximum or minimum responses, and significance of each involved factor, or their combination.

Furthermore, response surfaces can be used for calculating responses not only at experimentally investigated points, but also at any point on the surface [30]. In this work a three factor-three level Box-Behnken design, with 5 replicates at the center point, and 17 runs in total (Table 3.1)

[31]. Box-Behnken “BBD”: the minimum factor for this model is three to three levels. Each factor has only three levels. Good design properties, little co-linearity, rotatable or nearly rotatable; some have orthogonal blocks, insensitive to outliers and missing data. Use when region of interest and region of operability nearly the same.

3.2.7 Design of Experiment

A three variable Box-Behnken design for response surface methodology was used to study the combined effect of binder concentration, pressure and Dwell time on density over three levels. The range and level of the variables optimized are shown below in Table 3.1. The Box-Behnken design is suitable for the exploration of quadratic response surfaces and generates a second degree polynomial model, which in turn is used in optimizing a process using a small number of experimental runs. This design requires an experimental number of runs according to:-

$$N=K^2+K+C_p \tag{3.1}$$

Where:-

K: is the factor number which is 3 in this case

C_p: is the number of replications at the center point which is also 5 in this case.

The design which was developed using Design Expert® 7.0.0 trail version resulted in 17 experimental runs as shown in Table 3.2. The 17 experimental runs were randomized to maximize the effects of unexplained variability in the observed responses due to extraneous factors. The levels of the independent variables as shown in Table 3.1 were selected based on preliminary research done by many researchers. The research densification variables were varying pressure 40-80 bars based on [8] studies. The choice for clay binder ranges from 10-30% because of the previous study [14] which reported as the clay binder increases as the density increase but the volatile matter also increases which will reduce the calorific value. The dwell time ranges from 3-7 based on the study [14]. The relation between the coded and actual values is described as follows:

$$X_i = \frac{X_i - X_l}{\Delta X_i} \tag{3.2}$$

Where:-

X_i and X_i are the coded and actual values of the independent variable respectively

X_0 is the actual value of the independent variable at the center point

X_i is the step change of X_i

A second degree polynomial was fitted to the experimental data using the statistical package Design Expert® 7.0.0 to estimate the response of the dependent variable and predict the optimal point. The second degree polynomial was expressed as follows:

$$Y = b_0 + b_1 * X_1 + b_2 * X_2 + b_3 * X_3 + B_{12} * X_1 * X_2 + B_{23} * X_2 * X_3 + B_{11} * X_1^2 + B_{22} * X_2^2 + B_{33} * X_3^2 \quad (3.3)$$

Where:-

Y is predicted response,

X_1, X_2 and X_3 are independent variables,

b_0 is offset term, b_1, b_2, b_3 are linear effects, B_{11}, B_{22}, B_{33} are interaction terms.

Table 3-1: Coded and actual levels of the factors for three factors Box-Behnken design

Independent variables	Symbols	Coded and actual levels		
		-1	0	1
Pressure	X1	40	60	80
Dwell Time	X2	3	5	7
Binder Ratio	X3	10	20	30

3.2.8 Densification Equipment

The equipment used to produce briquettes was found from school of mechanical and industrial laboratory. And some other materials were from School of Chemical and Bio-energy engineering. Mould for Briquetting The mould was produced from Addis Ababa University, Mechanical Engineering laboratory. The mould used here using based on based on [32], [19], [29] research work specification 40 mm in diameter and 100 mm in height. The holes were produced 1/3 of the height to remove the water during densification.



Figure 3-8: Mould used for making briquettes manufacturing in laboratory

i. Binder Selection

The binder type and binder ratio have significant effect for the physic-chemical property of briquettes. Due to the availability of binder through the country clay were selected as a binder. In Ethiopia most briquettes manufacturing enterprise uses clay as a binder.



Figure 3-9: Red soils used as a binder

ii. Mixture Preparation

According to this [33] study the charcoal powder and water were mixed at the ratio of 3:7 by weight. In this study 10 gram mixed charcoal powder and clay were used. For binding this solid weight 23.3 gram of water was used. The mixture was heated for 15 minutes. The procedure used in this study was as follows. First put the 23.3 gram of water into the beaker and set on the stove after heating for 8 minutes. After the water heated for 8 minute the clay was poured in the

beaker and agitating thoroughly using a stick. Then agitating the solution for 3 minutes, then the solid biomass was poured into the water and the clay solution. Agitate the solution smoothly four minutes using stick to have uniformity in the charcoal powder and clay.



Figure 3-10: Mixtures of clay, charcoal powder and water on the stove

iii. Densification Process

Densification for these experiments was conducted using a laboratory hydraulic press. According to research [14] informed hydraulic press can use for making briquettes. In this research, hydraulic press that has 50 tones capacity was used for making briquettes.



Figure 3-11 Hydraulic press machines

iv. Drying of the briquettes

The briquettes after removing from the mold were put in the oven at 60 for 24 hours. Many research used oven for drying biomass briquettes [14].



Figure 3-12: Oven used to dry

3.2.9 Determining the Response Variable of Briquettes

Study figure out the main problem for utilization of biomass briquettes were transporting and handling/ storage and conclude that if the briquettes have high density it will solve handling problem. In this research density were used as the main criteria for selecting the optimal point for the densification process. If the density of briquettes were high, it would easily transport from the biomass rich area to the other less rich ones. The density was calculated using the formula:-

$$\text{Density} = \rho = \frac{m}{v} \quad (3.4)$$

Where:-

M= mass of briquettes after removed from the mould

V = volume of the briquettes

The volume was calculated using the formula:

$$V = A * L \quad (3.5)$$

Where:-

A=area of the briquettes $=\pi r^2$

L= the length of briquettes

The briquettes depth was measured using digital caliper



Figure 3-13: Digital clipper used to measure the briquettes thickness

For the purpose of optimizing multiple response variables, it is necessary to establish the optimal criteria in accordance to the Desirability Function (DF) approach, as proposed by [14]. The maximum or minimum value of the variable response is determined on the bases of technical and economical considerations. The general approach is to first convert each response Y_k into an individual desirability function $D_k=h_k(Y_k)$ that may vary over the range of.

$$DF = [\pi_1^3 * DK]^{1/3} \quad (3.6)$$

It is clear from Eqn 3.6 that DF will be close to 1.00 if all individual desirability functions are also close to 1.0. Therefore, $DF= .0$ implies that all response variables are at their respect optimum or target value condition. This type of methodology has been successfully applied to optimization of the mechanical densification process of agricultural crop residues for the production cattle feed [7].

3.2.10 Mass Balance Analysis

Mass balance analysis of briquettes was done for the best quality of briquettes to know the final yield of the briquettes process. This process was done by using input-output method that is an analysis of the mass flow in and out of each stage of processes.

3.3 Comparing Charcoal Briquettes with Wood Charcoal in Ethiopia

A preliminary assessment of biomass waste in Ethiopia was conducted by means of internet research and desk study to identify potential. A total of five potential was identified. Cotton stalk, coffee husk, bamboo, jatropha press cake and agricultural residue wastes were found the most available for substituting wood charcoal. From the above optional waste cotton stalk and bamboo charcoal briquettes Physico-chemical study were conducted in the Ethiopian rural development center (EREDPC). In this research the composite jatropha press cake and Agricultural residue charcoal briquettes were diagnosis to compare with cotton stalk, bamboo charcoals and wood charcoal.

3.3.1 Comparing Based on Biomass Resources

For the purposes of this study, biomass wastes were defined as organic residues, surpluses and by-products of agro-industrial processing, available in bulk.

i. Estimating the amount of crop residues

The most important parameter to consider for fuel production is the total amount of biomass potentially available across the country. In this study, four biomass wastes were identified and compared to support the objective. Biomass wastes were selected based on former study and total annual availability. Annual availability was done quantitatively using crop production statistics. The type and amount of agricultural residues available varies from crop to crop depending on the plant structure, seasonal availability, harvesting methods, irrigation practices, soil quality and other factors. But the amount of residues produced is directly related to the corresponding crop production. So if the crop production quantities at a particular time are known, it is possible to estimate the amounts of agricultural residues produced using the residue-to-product ratio (RPR)[34]. This method has been widely applied to estimate the potential availability of agricultural residues for energy generation [35]. Although this approach has its

limitations as it does not include future developments and investments in the agricultural sector; it is suitable to estimate the current country-specific energy potential of residues. The general equation for estimating the agricultural residual biomass is as follows:

$$R=C_p \cdot RPR \tag{3.7}$$

Where:-

R is the total available agricultural residual biomass in tones per year

C_p the amount of crop production in tones per year

RPR:- the residue-to-product ratio in tons of residues per tones of product

RPR of this residue was calculated based on historical trends in Ethiopia, and given the following values. See the following table. The data used for estimating the availability was obtained from 2003 E.C agricultural survey. Table 3.1 Crop to residue ratio estimation of selected biomass in Ethiopia

Table 3-2: Crop to residue ratio estimation of selected biomass in Ethiopia

	Biomass Wastes	Residue Ratio	Reference
Agricultural wastes	Barley	1.2	[1]
	Wheat	0.8	
	Maize	2	
	Sorghum	3	
	Rice Husk	0.8	
	Coffee Husk	1.41	[2]
	Cotton Stalk	2.75	
	Bamboo Residue	-	
	Jatropha Press Cake	0.75	

[1] Crop residue as potential energy in Africa

[2] Biomass used for Cement production in Ethiopia

At least 5,000 t. per annum of a given waste would need to be available to run a modest fuel production facility at commercial levels, meaning that total national production would need to be several times greater than this if multiple production units were to be supported.

ii. Degree of Centralization:

Bamboo residue, cotton stalk, coffee pulp, agricultural residue and Jatropha press cake biomass were investigated to know the centralization based on regional assessment. Assessing the resource availability based on Administration division helps to identify which resource was centralized in which region. Then the research predicated the possibility of producing charcoal from these wastes.

iii. Clarity of Ownership:

The ownership of a particular biomass waste must be clear and a supply arrangement should be agreed upon if a fuel production facility is to maintain control over its raw material. Certain biomass wastes have no defined owners and a user could be exposed to opportunistic pricing. When biomass produced by large industry is available from assured sources on a relatively reliable basis, a supply can be guaranteed through a written contract.

iv. Absence of Annual or Seasonal Variations in Supply:

Where the ultimate intention is to establish a full-time fuel production facility based on a particular type of waste, it is important that the waste should be available in consistent quantities on a year-round basis..

v. Absence of pre-existing or competing uses:

A given biomass waste might be produced in large quantities but could have a pre-existing use. Maize cob for example, is an abundant resource in Ethiopia but is used as dry season cattle fodder and for cooking is sold for up to 750 Birr (USD 40)/t. Many crop residues are left in the field after harvest to enhance moisture conservation and recycle nutrients. Some may actually have an associated disposal cost and therefore represent a negative asset for their producers.

3.3.2 Comparing Charcoal Briquettes Based on Fuel Characterization

The composite charcoal briquettes were produced based on the optimal result of design expert software .Then, the briquettes were randomly selected, fuel characteristics analyzed and compared with charcoal briquettes and wood charcoal. Fuel characterizing was done using ASTM standard by making Briquetting at optimal points of pressure P, dwell time D & binder concentration BR.

i. Physical Characterization of Composite Charcoal Briquettes

The strength and density was determined by measuring their mass and dimensions after removal from the Briquetting machine.

ii. Proximate Property Determination Method

Proximate analysis consists of percentage volatile matter, content, percentage ash content, moisture content and the percentage content of fixed carbon of the briquettes. The proximate analysis standardized procedure that tells the bulk components that make up a fuel [36]. The above four analyses were done ASTM standard [37].

a) Percentage Moisture Content

The percentage moisture content (PMC) was found by weighing 2 g of the briquette sample (E) and oven drying it at 105°C until the mass of the sample was constant. The change in weight (D) after 60 min was then used to determine the sample's PMC using Equation 3.8:

$$PMC = \frac{D}{E} * 100 \quad (3.8)$$

b) Percentage Volatile Matter

The percentage volatile matter (PVM) was determined by pulverizing 2 g of the briquette sample in a crucible and placing it in an oven until a constant weight was obtained. The briquettes were then kept in a furnace at a temperature of 550°C for 10 min and weighed after cooling in desiccators. The PVM was then calculated using Equation 3.9:

$$PVM = \frac{(A-B)}{A} * 100 \quad (3.9)$$

Where:-

A is the weight of the oven-dried sample

B is the weight of the sample after 10 min in the furnace at 550°C.

c) Percentage Ash Content

The percentage ash content (PAC) was also determined by heating 2 g of the briquette sample in the furnace at a temperature of 550°C for 4 h and weighed after cooling in desiccators to obtain the weight of ash (C). The PAC was determined using Equation 3.10:

$$\text{PAC} = C/A * 100 \quad (3.10)$$

d) Percentage Fixed Carbon

The percentage, fixed carbon (PFC) was computed by subtracting the sum of PVM, PAC and PMC since 100 as shown in Equation 3.11:

$$\text{Fixed Carbon} = 100 - (\text{PAC} + \text{PMC} + \text{PVM}) \quad (3.11)$$

3.3.3 Comparing Charcoal Briquettes Based Heating Value

The calorific value was determined using a bomb calorimeter in accordance with [43] ASTM 2015 [44] the energy content or calorific value of oven-dried biomass was determined in a bomb calorimeter.

3.3.4 Comparing charcoal briquettes based on Combustion Characteristic

Heating quality analysis was done by using normal charcoal stoves. The fuel was put on the stove. The method in this analysis was Water Boiling Test (WBT) by boiling one liter of water. WBT is a simulating method of fuel combustion process to examine how effective the thermal energy can be transferred to the stove for heating purposes [45]. Combustion Rate: Combustion rate of fuel briquettes is the time required for complete combustion of a known quantity of briquettes [20]. Ignition timing was determined by burning 200 g of briquettes on charcoal stoves. Since the end-point of lighting was subjective and depended on ones judgment according to what stage the ignition has been achieved, two similar charcoal stoves were ignited at the same time by placing equal amounts of paraffin on the floor of the charcoal stoves and lighting using a lighter. In this process, ignition time was taken as the average time taken to achieve steady glowing fire [14]. Water Boiling Test: Burning time was measured as time taken from the moment briquettes ignite until they completely burn out. 200 g of the composite briquettes was burnt in charcoal stoves and the burning time was measured [12].

3.3.5 Comparing Based on Environmental Emission

This research compared the production of charcoal in two cases. The first one was the production of wood charcoal in traditional method as a baseline scenario and the second was production of charcoal briquettes as a project scenario.

i. Baseline Scenario

The baseline scenario refers to the unimproved charcoal production process used by the project entity prior to project implementation. The methane emissions associated with the baseline scenario are estimated based on the weighted average gravimetric yield achieved using the unimproved charcoal production process. Based on approved methodology AM0041 (CDM – approved Methodology) assessing the baseline gravimetric yield and the equations 3.12 and 3.13 below are used to estimate the baseline methane emissions.

$$M(b) = 139.13 - 313.80 * Y(b) \quad (3.12)$$

Where,

M(b) = Methane emissions factor in the baseline scenario (kg of CH₄/ton of charcoal)

Y(b) = Baseline weighted average carbonization gravimetric yield (ton of charcoal/ton of wood)

The baseline emissions in tons of CO₂ equivalents can be estimated by multiplying the methane emissions factor Mb of the equation 3.6 with the CH₄ global warming potential, and the amount of charcoal produced under the project activity on a dry weight basis.

$$BECO_2e = M(b) / 1000 * GWP_{CH_4} * CP \quad (3.13)$$

Where,

BECO_{2e} = Total baseline emissions in CO₂ equivalent (tons/ time period)

GWP_{CH₄} = Global warming potential of methane = 21

CP = Amount of charcoal produced (ton / time period)

ii. Project Scenario

The project implementation allows for the adoption of improvements in carbonization process and thereby achieves emissions that are lower than those observed under the baseline scenario. The extent of the reduction in methane emission depends on the efficiency of technical and operational changes that are implemented and reflected in the improvement of the carbonization gravimetric yield Y(p). Therefore, all measurements and calculations will be recorded using spreadsheet, database and will be available to the DOE at the time of verification and validation.

The following equation is used to calculate the coefficient of variation of gravimetric yield in the project scenario: This project monitoring procedures will help in the accurate assessment of gravimetric yield and ensure the implementation of measures that will enhance the gravimetric yield, reducing the methane emissions by consequence,

$$M(p) = 139.13 - 313.80 * Y(p) \quad (3.14)$$

Where,

M(p) = Methane emissions factor of the project scenario (kg of CH₄/ton of charcoal)

Y(p) = Carbonization gravimetric yield (ton of charcoal/ton of wood, dry basis) based on the monthly weighted average of charcoal production.

The project emissions in tons of CO₂equivalent can be estimated by multiplying the amount of emissions by the CH₄ global warming potential and the charcoal production on dry weight:

$$PECO_2e = M(p) / 1000 * GWP_{CH_4} * CP \quad (3.15)$$

Where,

PECO_{2e} = Total project emissions in CO₂ equivalent (tons/period of time)

GWP_{CH₄} = Global warming potential of methane = 21

CP = Amount of charcoal produced (ton / period of time)

4. Chapter Four

Analysis for Composite Charcoal Briquettes

4.1 Raw Material Characteristics Analysis

For the purpose of property analysis, the materials were dried in the sun to reduce their moisture content to less than 14% (w/w). Then, they were reduced in size to a uniform particle of 2-3 mm length of agricultural straw and 1.5 mm for jatropha press cake (JPC). The proximate analysis parameters were moisture content, ash content, volatile matters, fixed carbon and calorific value. The result of this analysis is presented in Table 4.1.

Table 4-1: Proximate analyses of raw material

Property	Unit	Value	
		Agricultural Residue (AR)	Jatropha Press Cake (JPC)
Moisture	% w/w	8.2	11
Ash	% w/w	7.48	5.88
Volatile matter	% w/w	74.39	66.8
Fixed carbon	% w/w	9.94	16.32
Calorific value	KJ/kg	17299.99	17559.98

The moisture contents of agricultural residue and jatropha press cake (8-12%) meet the requirement as described by many briquettes researchers [12]. This indicated that briquettes would have high density, durability and calorific value. The main parameter to determine the heating quality of briquettes is the calorific value of the materials. The calorific values of these materials were higher than those of cotton stalk (16709.52 KJ/kg), Bamboo leaves (15725.62 KJ/kg) and Prosopis (17739.47 KJ/kg) [41]. In addition to calorific value, they contain high volatile substances and ash [11]. Thus, converting them into charcoal briquettes could reduce both volatile substances and ash together with increasing fixed carbon content.

Carbonization Analyses of Jatropha Press Cake and Agricultural Residue

Carbonization is biomass combustion with limited oxygen to increase its calorific value and fixed carbon content. Lack of oxygen will push out volatile substances, while carbon components will stay in the material. Carbonization of jatropha press cake and agriculture residue at a temperature of 400 for 15 minutes and 450 for 45 minutes, yielding 30% (w/w) of its original weight respectively. The results of proximate analysis of agricultural residue and jatropha press cake charcoal are presented in Table 4.2.

Table 4-2: Proximate analysis of carbonized powder

Properties	Unit	Value	
		Agricultural Residue	Jatropha Press Cake
Moisture	% w/w	4.25	4.5
Ash	% w/w	6.03	8.07
Volatile matter	% w/w	33.41	11.48
Fixed carbon	% w/w	56.31	75.95
Caloric value	KJ/kg	21448.98	23224.18

The moisture content and volatile substances were reduced during the carbonization process; whereas fixed carbon content and the calorific value were increased. The moisture content was evaporated at high temperature, but when it is taken out of the process, it absorbs moisture from the environment due to its hygroscopic characteristic. The charcoal surface has empty pores, thus its particles are easily released and absorb water depending on environmental conditions [42].

4.2 Production of Composite Charcoal Briquettes of JPC and AR

The charcoal briquettes produced from Agricultural residue and the jatropha press cake was used for response surface optimization. Charcoal briquettes were manufactured by combining pressure (P), dwell time (D) and clay concentration ratio (BR) factors to determine the density (response variable). Based on design expert software, combinations of dwell time, pressure and clay concentration 17 composite charcoal briquettes were produced .see the Figure below.



Figure 4-1: Composite charcoal produced based on combination P, DT, BR

The composite charcoal briquettes were produced in the ratio of 25% agricultural residue and 75% jatropha press cake by solid weight. This is due to the abundant availability of jatropha press cake; this had not been used before. After the briquettes were removed from the mould, the length and weight of the briquettes were measured using vainer caliper and digital balance. The actual density of the composite charcoal briquettes was calculated using Equation (3.12) and values were put in the Table below. These 17 composite charcoal briquettes were produced using 75 % of jatropha press cake and 25% agricultural residue.

Table 4-3: Three factor Box-Behnken design with experimental as well as predicted responses of dependent variable (density, kg/cm³)

Run	Block 1	Factors			Factor			Actual Density	Predicted Density
		Coded			Actual				
order		X1	X2	X3	A: Pressure	B: Dwell	C: binder	(1000kg/m ³)	1000Kg/m ³)
1	Block 1	0	-1	-1	60	3	10	0.789	0.786
2	Block 1	1	1	0	80	7	20	1.133	1.115
3	Block 1	0	1	1	60	7	30	1.171	1.173
4	Block 1	1	0	1	80	5	30	1.133	1.148
5	Block 1	-1	1	0	40	7	20	1.075	1.078
6	Block 1	-1	0	-1	40	5	10	0.783	0.767
7	Block 1	0	0	0	60	5	20	1.041	1.059
8	Block 1	0	0	0	60	5	20	1.056	1.059
9	Block 1	0	0	0	60	5	20	1.07	1.059
10	Block 1	0	1	-1	60	7	10	0.844	0.857
11	Block 1	0	0	0	60	5	20	1.069	1.059
12	Block 1	1	0	-1	80	5	10	0.87	0.876
13	Block 1	-1	0	1	40	5	30	1.187	1.181
14	Block 1	0	0	0	60	5	20	1.061	1.059
15	Block 1	-1	-1	0	40	3	20	1.014	1.033
16	Block 1	1	-1	0	80	3	20	1.075	1.072
17	Block 1	0	-1	1	60	3	30	1.168	1.156

4.3 Response Surface Method (RSM) Analysis

The results obtained from the 17 experimental runs carried out according to the Box- Behnken design is summarized in Table 4.3. The proposed second degree polynomial was fitted to the data presented in Table 4.3 using multiple linear regressions to determine the optimum densification conditions that resulted in the maximum density of the briquettes. The effects of binder concentration, pressure and dwell time were quantitatively evaluated using response surface curves. By applying multiple regression analysis on the experimental data, the following second degree polynomial was found to represent the relationship between the density of briquettes and binder concentration, pressure and dwell time adequately.

$$\text{Density} = Y = +1.06 + 0.019 * A + 0.022 * B + 0.17 * C - 6.477E-004 * A * B - 0.035 * A * C - 0.013 * B * C + 7.488E-003 * A^2 - 7.717E-003 * B^2 - 0.074 * C^2 \quad (4.12)$$

The predicted levels of density of charcoal briquettes using Equation (4.12) are given in Table 4.3 along with the experimental data. The significance of the fit of the second-order polynomial for the density of briquettes was assessed by carrying out an analysis of variance (ANOVA) with results shown in Tables 4.4 and 4.5.

Table 4-4: Statistical information for ANOVA analyses

Source	Response Value
R-Squared	0.99
Adj R-Squared	0.98
Standard deviation	0.0175
C.V %	1.69
Adeq Precision	30.81

The coefficient of determination (R²) of the model was 0.99 (Table 4.4), which indicated that the model adequately represented the real relationship between the variables under consideration. An R² value of 0.99 means that 99.007% of the variability was explained by the model and only 1.00% was as a result of chance. The coefficient of variation (C.V.) obtained was 1.69%. The Coefficient of Variation (C.V) indicates the degree of precision with which the treatments were carried out. A low value of C.V suggests a high reliability of the experiment [43]. Adequate precision value (40.382) measures the signal to- noise ratio and a ratio greater than 4 is generally desirable [44]. The "Lack of Fit" F-value of 3.70 implies that there is an insignificant lack of fit. The "Lack of Fit" (Prob. > F) value of 0.1192 implies that there is only 11.92% chance that the "Lack of Fit" F-value could occur due to noise. Results obtained after carrying out ANOVA are presented in Table 4.5.

Table 4-5: ANOVA for response surface quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.27099	9	0.03011	98.086788	< 0.0001	significant
A-Pressure	0.00287	1	0.00287	9.3608978	0.0183	
B-dwell Time	0.00384	1	0.00384	12.510928	0.0095	
C-clay Binder	0.23557	1	0.23557	767.39857	< 0.0001	
AB	1.70E06	1	1.70E-06	0.0054657	0.9431	
AC	0.00502	1	0.00502	16.357992	0.0049	
BC	0.0007	1	0.0007	2.2767366	0.1751	
A^2	0.00024	1	0.00024	0.7689811	0.4096	
B^2	0.00025	1	0.00025	0.8169404	0.3961	
C^2	0.02286	1	0.02286	74.466102	< 0.0001	
Residual	0.00215	7	0.00031			
Lack of Fit	0.00158	3	0.00053	3.7022888	0.1192	not significant
Pure Error	0.00057	4	0.00014			
Cor Total	0.27314	16				

Value of “Prob. > F” < 0.05 indicate that the model terms are significant. Values > 0.10 indicate that the model terms are not significant. The Model F-value of 98.08 and very low probability value [(Prob > F) <0.0001] implies the model is significant. Prob > F values less than 0.0500 indicate model terms are significant. From the regression density model, A,B,C, C2 is significant with probability of 95%.The term AC is significant, indicating that there was interaction between binder concentration and pressure with density. The interaction between the terms AB,BC,A2 and B2, however had no significant effect on the density of briquettes. There is a 84.4% chance that a "Lack of Fit F-value" could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

4.4 Validation of the Model

It is clearly seen from the Mat-lab plot (Figure 4.2) below. The values are in the graph on both sides of the line indicating that the experimental data are in excellent agreement with the predicted values.

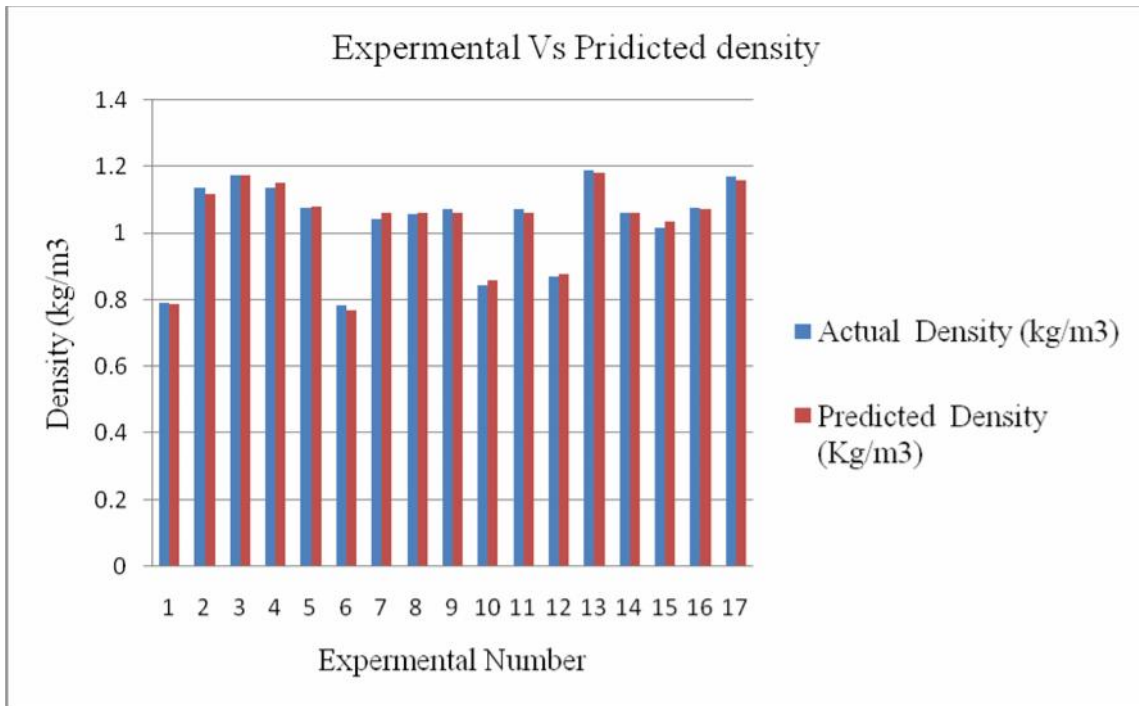


Figure 4-2: Validation Experimental value with modeled value

The above finding indicates the outstanding adequacy of the proposed quadratic model to represent the variable response of density of briquettes at a pressure of 40-80 bars, Dwell time: 3-7 minute and clay binder 10-30%. The predicted and experimental data for the response variables of density of the solid fuel shows nearly equal value

4.5 Effect of Process Variable on Density of Briquettes

The effect of the three process variables (pressure, dwell time and clay binder ratio) were investigated over the density model and the result were plotted here after. The interaction effect of the two processes was investigated at one graph. The total of three graph were plotted and the graph trends were shown in the below.

4.5.1 The Effect of Pressure and Dwell Time on Density of briquettes

Pressure and the dwell time increase as the density increases see figure 4.3 and 4.4 below. The density of the briquettes varies from 1.046-1.101 kg/cm³ with the increase in dwell time and pressure from 3-7mnuite, 40-80bars respectively. Using the same density line, as the pressure increases, the dwell time decreases. From the graph below, as the pressure increases from 40-60, the dwell time decreases from 4.5-3.2 minutes. The density of briquettes is greater than 1.00g/cm³. Then, the briquettes can have high potential to resist disintegration during transport [8]. To get density greater than one, the time should be greater than 5 minutes. Many researchers agreed that the dwell time should be greater than 5minutes when the pressure is greater than 50 bars [14] .This research has shown a result consistent with the above finding (the dwell time and the pressure greater than 5 minute and 50 bar respectively, the point lie on the curve whose density was greater than 1.04 the first density line.)

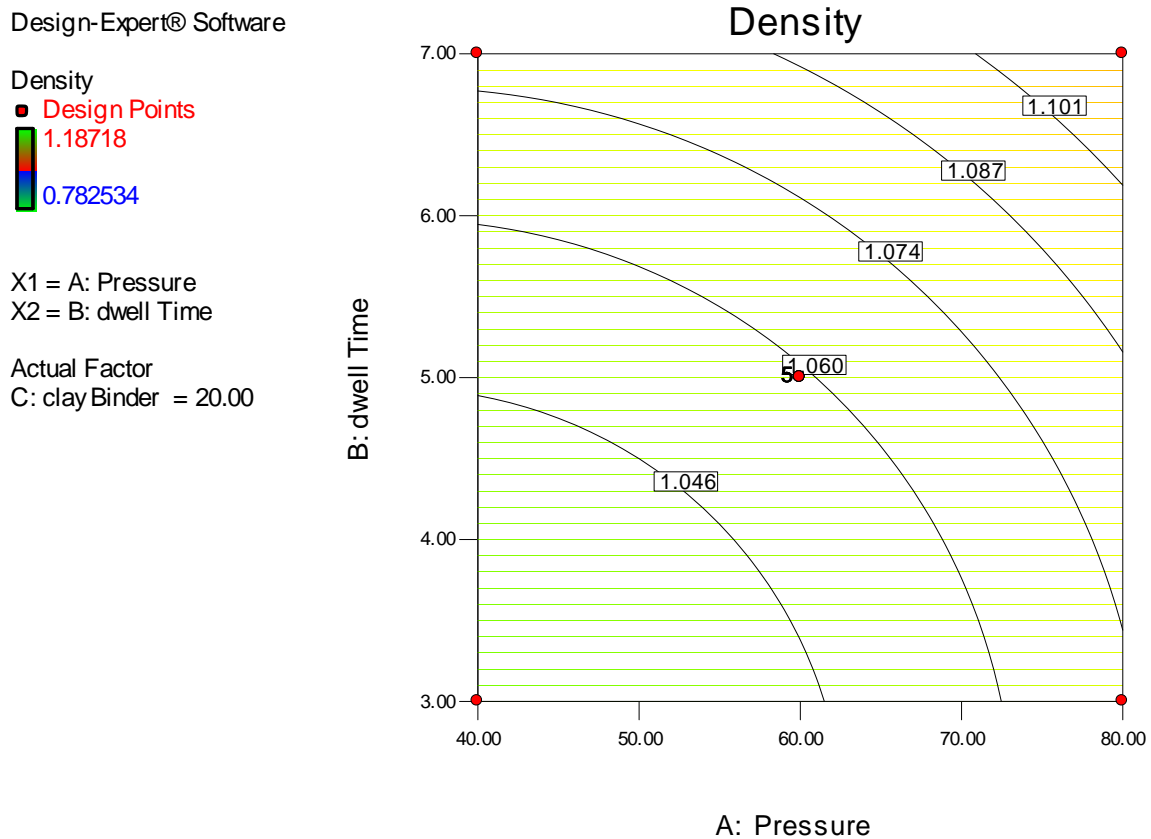


Figure 4-3: A counter plot for the interaction effect of pressure and dwell time on density model

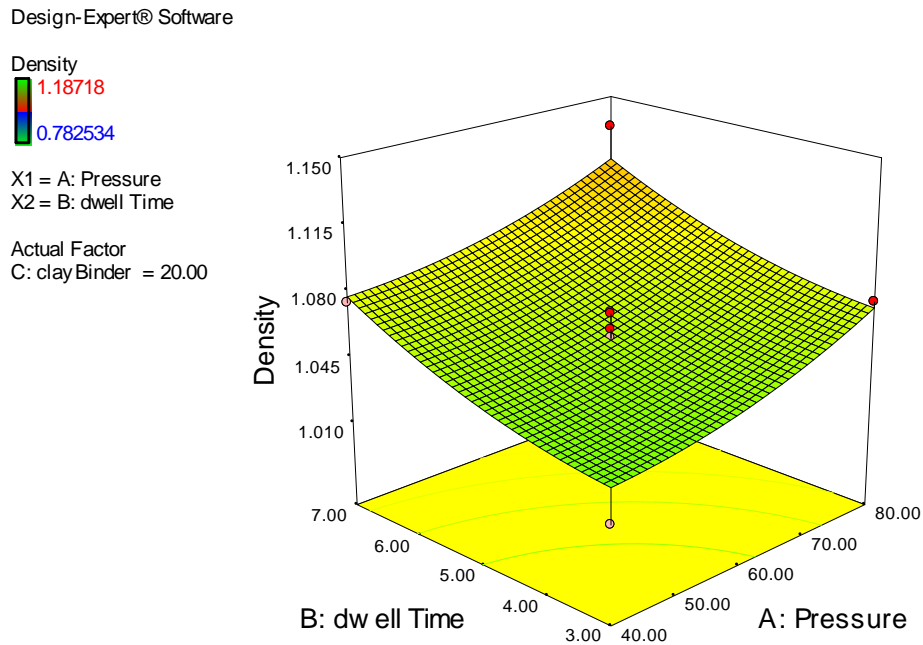


Figure 4-4: 3D plot for interaction effect of pressure and dwell time on density model

4.5.2 The Effect of Pressure and Clay Binder over Density of Briquettes

As seen since 4.5 and 4.6, the density of the briquettes was found in the range of 0.836-1.112 g/cm³ as the pressure and the clay binder varied (varies) from 40-80 bars and 10-30%. Many researchers agreed that the pressure and the binder ratio have direct relation [14]. This finding also has shown that the density increases as the binder ratio increases. But in this finding, as seen in figure 4.5 below is taken the same density line, as the pressure increases, the clay binder decreases directly.

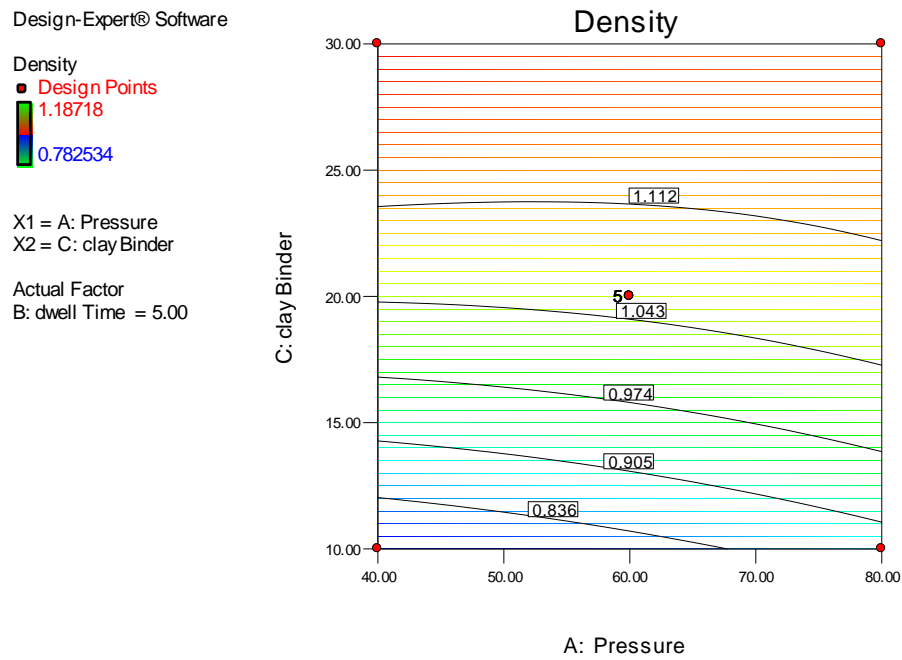


Figure 4-5: Counter plots for interaction effect of pressure and clay binder on density model

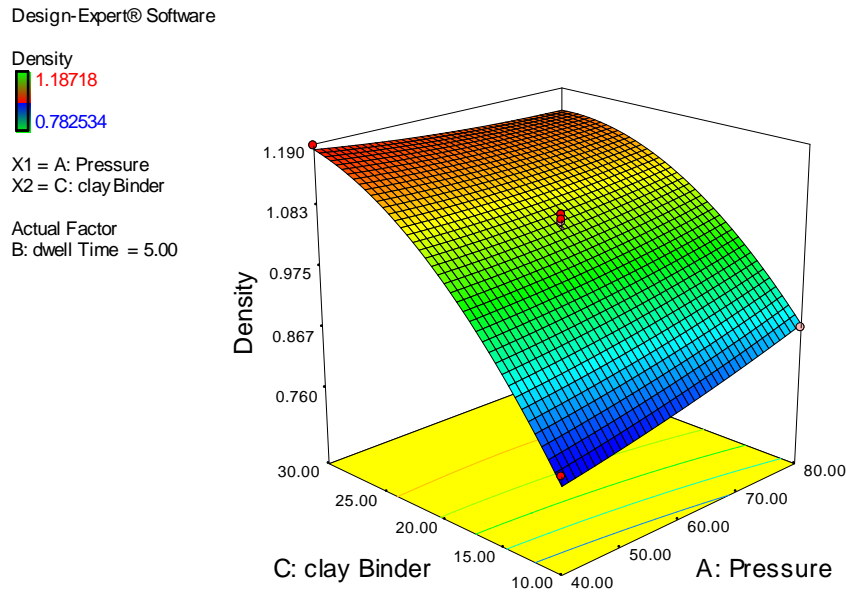


Figure 4-6: 3D plot for interaction effect of pressure and clay binder on density model

4.5.3 The Effect of Dwell Time and Clay Binder over Density

As seen from Fig 4.7 and 4.8, the density of briquettes varies from 0.851g/cm³-1.10g/cm³ as the clay binder and dwell time increase from 10-30% and 3-7 minutes respectively. Taking the same density line, as the dwell time increases, the clay binder ratio decreases. Dwell time or hold time is the duration for which the material is subjected to the highest pressure during the densification process [45]. Studies have shown that an increase in dwell time leads to an increase in the dry density of biomass of briquettes [46].

Design-Expert® Software

Density
 ● Design Points
 1.18718
 0.782534

X1 = B: dwell Time
 X2 = C: clay Binder

Actual Factor
 A: Pressure = 60.00

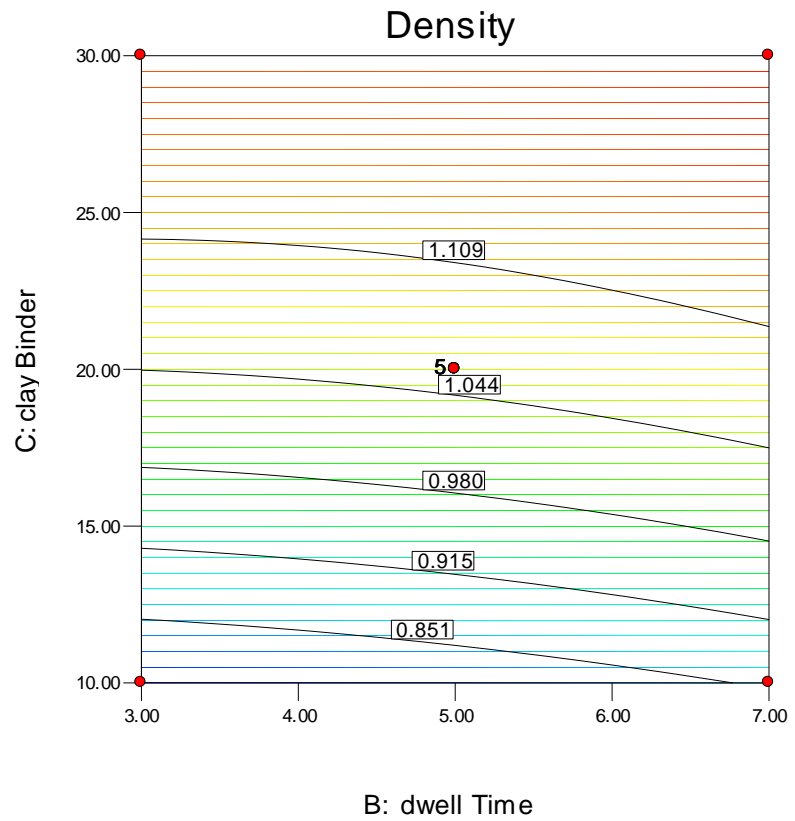


Figure 4-7: Counter plot for interaction effect of dwell time and clay binder on density model

Design-Expert® Software

Density
 1.18718
 0.782534

X1 = B: dwell Time
 X2 = C: clay Binder

Actual Factor
 A: Pressure = 60.00

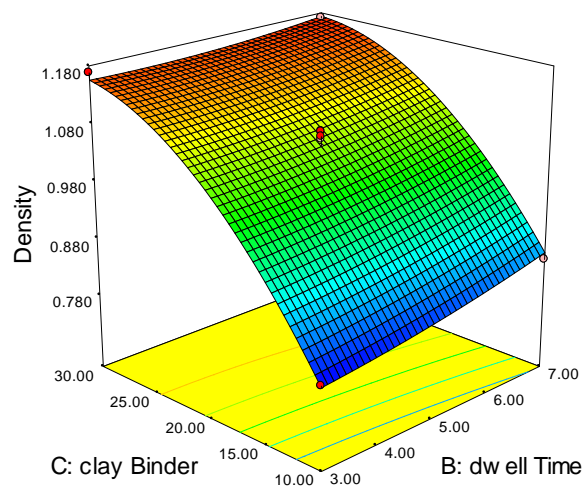


Figure 4-8: A counter plot for interaction effect of dwell time and clay binder on density

4.6 Optimization of Density Model

Determining the optimum operating conditions for the charcoal briquettes is aimed at obtaining a high quality of solid fuel at a minimum operating cost of production. One feature of high quality briquettes solid fuel is indicated by its density of higher than 1.00 g/cm³. Minimum operating cost can be achieved when the pressure is at (X1= 40-60bar), dwell time X2 < 5 minutes and clay binder concentration X3=10-25%. The second order polynomial model to represent the density response variables was utilized to target to have a density of the operating conditions of the independent variables. Table4.6 Constraints used for optimizing the density model

Table 4-6: Constraints used for optimizing the density model

Name	Goal	Lower Limit	Upper Limit
Pressure	is in range	40	80
Dwell Time	is in range	3	7
Clay Binder	is in range	10	30
Density	is target = 1.050	0.8	1.2

The target density was found from the mean of 0.783 g/cm³ and 1.18 g/cm³. 1.032 g/cm³ density was the mean of the minimum and maximum (0.783 and 1.18g/cm³ respectively). This model is merely valid in the selected experimental domain. In this study, pressure, clay binder concentration and dwell time were chosen in the range of 40-80 bars, 3-7 dwell time, and clay binder 10-30% .see the fig below. Applying the desirability function (DF) Method, the design Expert software product (a number of) 13 solutions (of which) each having DF=1, as shown in Table 4.7. However, among 13 solutions, only three meet the predetermined criteria. The first is 46.23 bar Pressure, 18.27% clay binder concentration and 3.6 minute dwell time. The second is 47.21bar pressure, 18.01% clay binder concentration and 4.21 minute dwell time. The last selected was with 44.96 bar pressure, 18.18 clay binder concentrations and 3.97 minute dwell time. The first, the second and the third give the density of 1.05 as targeted value. From the above three optimal pints the first option was selected to be the best point. Table4.7 Design expert software selecting criteria

Table 4-7: Design expert software selecting criteria

Number	Pressure	Dwell Time	Clay Binder	Density	DF	Criteria	Judgment
1	46.23	3.6	18.27	0.9999987	1	X1<50 & X2<5	Accepted
2	70.86	3.65	16.73	1.000001	1	X1>60	Rejected
3	46.01	6.19	16.9	0.9999984	1	X2>5	Rejected
4	76.12	5.88	14.85	0.9999982	1	X1>60	Rejected
5	47.24	4.21	18.01	1.0000014	1	X1<50 & X2<5	Accepted
6	76.57	4.99	15.46	0.999998	1	X1>60	Rejected
7	44.96	3.97	18.18	1.0000009	1	X1<50 & X2<5	Accepted
8	73.45	3.8	16.42	0.9999985	1	X1>60	Rejected
9	52.87	3.78	17.94	1.000001	1	X1<50 & X2<5	Accepted
10	57.47	6.72	15.83	1.0000013	1	X2>5	Rejected
11	52.52	3.46	18.06	1.0000011	1	x2>50	Rejected
12	58.91	5.48	16.71	1.0000011	1	X1>60	Rejected
13	65.1	5.19	16.45	1.000001	1	X1>60	Rejected

The best from the above ratio at P= 46.23bar, dwell time 3.6 and clay binder 18.27%

Validation of Optimum Point:-The adequacy of the model was examined by an additional experiment using the derived optimal conditions. The optimal conditions used to be pressure=45 bar, dwell time=3.6minute and clay binder concentration (18.27%). The pressures used were 45bar to avoid the celebration error of the pressing machines which was hard to read 46.23 bars. The predicted value was 1.05g/cm³ and the experimental value was 0.998, average of three experiments. This is approx. 95% of the predicted value, which indicates that the generated model is an adequate prediction of the Density of briquettes.

4.7 Mass Balance Analysis

The mass balance analysis was conducted to determine the yield of each stage of the manufacturing process, starting from milling, screening, carbonizing, mixing, briquetting, and drying. The simple rule was a calculation of the ratio. Between the mass came (input) and out (output) in each stage of processes at laboratory scale. See fig below.

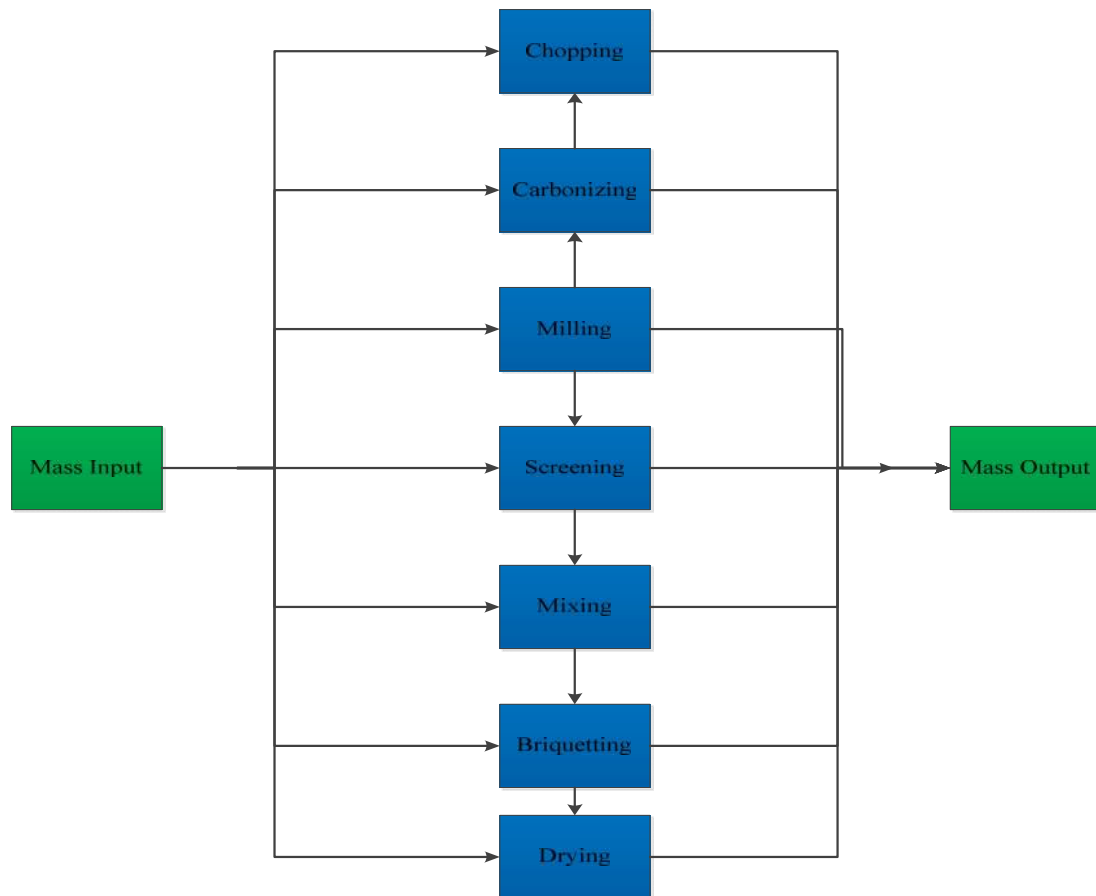


Figure 4-9: The process flow of briquettes plant

Figure 4.9 The Process Flow of Briquettes Plant Agricultural residues of 10kg, 8 kg of and jatropha press cake was processed, yielding about 2.58 and 2.06 kg respectively after the end of the above seven processes. The mean yield of the chopping, carbonization, milling, screening, mixing, densification, and drying was 95.3%, 30%, 96.4%, 99%, 99%, 98.7% and 96% respectively. The calculation part is as follow.

Agricultural residues of 10kg, 8 kg of and jatropha press cake were processed, yielding about 2.58 and 2.06 kg respectively after the end of the above seven processes. The mean yield of the chopping, carbonization, milling, screening, mixing, densification, and drying was 95.3%, 30%, 96.4%, 99%, 99%, 98.7% and 96% respectively. The calculation part is as follows.

Table 4-8: Efficiency of each process for briquetting industry

Process	Jatropha Press Cake		Agricultural Residue		Efficiency
	Biomass In	Biomass Out	Biomass In	Biomass Out	
Chopping	8kg	7.65	10	9.5	95.3
Carbonizing	7.65	2.29	9.5	2.85	30
Milling	2.29	2.2	2.85	2.76	96.4
Screening	2.2	2.18	2.76	2.74	99
Mixing	2.18	2.16	2.74	2.71	99
Briquetting	2.16	2.12	2.71	2.68	98.7
Drying	2.12	2.06	2.68	2.58	96

4 Chapter Five

Economics Evaluation to Production Composite Charcoal Briquettes

5.1 Cost Consideration

5.1.1 Plant Capacity

Table 5-1: Production capacity of a plant

Effective operating days	250days/yr
Effective operating hrs/shift	8hr/shift
Shift per day	1shift/day
capacity factor	20%
Effective operating hrs/yr	2000hr/year
Briquetting	75kg/hr= 0.075ton/hr
Annual production(t/yr)	1300ton/year
Raw material inputs	
Charcoal powder Jatropha press cake	$0.82*0.75*1300=922.5\text{ton/yr}$
Charcoal powder of Agricultural residue	$0.82*0.25*1300=307.5\text{ton/yr}$
Clay binder	$0.18*1300=270\text{ton/year}$
Water	270ton/yr

Production Program

The envisaged production program is given in Table 5.2 below. The schedule is worked out in consideration of the time required for gradual build-up in market, labor productivity and fine-tuning of machinery. Production starts at 75% of plant capacity in the first year of operation and reaches full-gear in the 3rd year of operation and then after.

Table 5-2: Production program

year	1	2	3-12
Capacity Utilization [%]	75	80	100
Production [Tones]	975	1048	1300

5.1.2 Materials and Inputs

Raw Materials

The required raw materials are agro wastes, agricultural residues and Jatropha press cake. To produce one ton of charcoal briquettes, about 1.4 tons of raw materials are required; 30% is allowed for carbonization and 10% for moisture content wastage. The finished briquettes are supposed to be packed in 50-kg PP-bag, which is distributed by wholesalers to retailers who then can re-pack the product in cheap PE sachets or sell in bulk to consumers. The major agricultural residues that could be obtained in all parts of Ethiopia and Jatropha press cake were available. Table 5.3 shows annual raw material requirement and associated costs at full production capacity. The total annual cost of raw materials is estimated to be Birr 232,780.00

Table 5-3: Annual materials requirement and cost

no	Description	Unit of Measure	Qty	Unit Cost (Birr)	Total Cost (Birr)
1	jatropha waste	tones	3,075	148	455941
2	Agricultural waste	tones	1,025	148	151,980
3	Red soil	tones	270	148	40033
4	PP bags	pieces	26,000	2.23	57980
Grand Total					705,936

Jatropha cake cost, agricultural residue and Red soil the only cost of these materials was transported 148 Birr/tonne.

Utilities

Electricity and water are the two major utilities required by the plant. Table 5.4 below shows annual requirements and associated costs at full production capacity. The total annual cost of utilities is estimated to be 93,408 birr.

Table 5-4: Annual utilities requirement and costs

No	Description	Unit of Measure	Qty	Unit Cost Birr	Total Cost
1	Electricity	kWh	400,000	0.6943	85158
2	Water	m3	1500	5.5	8250
Grand total					93408

5.1.3 Technology and Engineering

Technology:-Production Process

The fuel Briquettes are made out of loose agro-wastes into a compressed form to increase their specific weight, thus increasing the fuel efficiency (combustion efficiency) as compared to its loose condition. Technologies required binders in the production of briquettes from Jatropha press cake and agricultural residue.

Source of Technology

The Machine capacity: - Capacity=75kg/hr, Motor 7,5kW, 400 V, 50 Hz; Brikett DM 70 mm with Capacity of 60-80kg/hr depending on the material used.

Engineering Machinery and Equipment

The list of machinery and equipment required to manufacture fuel briquettes is given in Table 5.1 below. On this basis, total cost of machinery and equipment is estimated to be Birr 560,000 out of which Birr 460,000 was required in foreign currency. Land, Building and Civil Works Total land requirement of the project is estimated to be 1,000 m², out of which 500m² is built-up area. Cost of building construction at a unit cost of Birr 1800 per m² is estimated to be Birr 500,00 .Total land lease cost, for a period of 80 years land holding and at a lease rate of Birr 0.10 per m², is estimated at be Birr 12,000. Thus, the total investment cost of land, building and civil works assuming that the total land lease cost will be paid in advance is estimated to be Birr 512,000. Proposed Location The availability of raw material is a key factor for the determination of the location of the plant. The other factors are availability of markets and infrastructure. Considering the above factors, the location of the envisaged plant is proposed to be in bati or Arti and global districts.

5.1.4 Manpower and Training Requirements Manpower Requirement

Total manpower requirement include skilled and unskilled labor. Correspondingly, the total annual labor cost including fringe benefits, is estimated to be Birr 189,200. Table 5.5 below shows the list of manpower required and the estimated annual labor costs.

Table 5-5: Industrial briquetting: - personal requirements and costs

	Shift Composition	Shifts/Day	Monthly Wage
Administration personnel	1		
Plant manger	1	1	ETB 3,260
Plant personnel	16		
Plant technician	1	1	ETB 1,800
Unskilled labor			
Grinder	1	1	ETB 1,300
Briquette	10	1	ETB 1,300
Drying	2	1	ETB 1,300
Sacking	2	1	ETB 1,300
Total	18		21,960/Month
Worker's Benefit = 25% of Basic Salary			5490/month
Total /year			390,120 ETB/yr

Unskilled laborer is paid on a day basis (50ETB/DAY) and only during the 250 annual operational days.

Training Requirement An on-site training program can be arranged for key production, maintenance and quality control personnel in consultation with the machinery and technology supplier. The training can be best carried out during commissioning and performance testing of the factory. The cost of such training is estimated to be Birr 20,000 and will take about two weeks.

5.1.5 Financial Analysis

The financial analysis of the fuel briquette project is based on the data presented in the previous chapters and the following assumptions:-

Table 5-6: Assumption values

Construction Period	For 1 Year Starting Date 2014 Year
Source of Finance	30 % Equity
	70 % Loan
Tax Holidays	3 Years
Bank Interest	8%
Discount Cash Flow	8.50%

5.2 Total Initial Investment Cost

The total investment cost of the project, including working capital is estimated to be Birr 1.9387 million, of which 9 per cent will be required in foreign currency. The major breakdown of the total initial investment cost is shown in Table 5.7

Table 5-7: Initial investment cost

No.	Cost Items	('000 Birr)
1	Land lease value	12
2	Building and Civil Work	500
3	Plant Machinery and Equipment	560.8
4	Office Furniture and Equipment	100
5	Vehicle	400
6	Pre-production Expenditure*	220.9
7	Working Capital	120
	Total Investment cost	1,913.7
	Foreign Share	9

N.B -Pre-production expenditure includes interest during construction (Birr 100.90 thousand) training (Birr 20 thousand) and Birr 100 thousand costs of registration, licensing and formation of the company including legal fees, commissioning expenses, etc.

5.2.1 Production Cost

The annual production cost at full operating capacity is estimated to be Birr 1.2 million (see Table 5.8). The material and utility cost accounts for 71.37 per cent, while repair and maintenance take 4.17 per cent of the production cost.

Table 5-8: Annual production cost at full capacity ('000 Birr)

Items	Cost	%
Raw Material and Inputs	705.936	63.03
Utilities	93.408	8.34
Maintenance and repair	46.704	4.17
Labour direct	32.928	2.94
Total Operating Costs	65.744	5.87
Depreciation	120.176	10.73
Cost of Finance	55.104	4.92
Total Production Cost	1,120	100

5.3 Financial Evaluation

The internal rate of return (IRR) and the net present value (NPV) of the project are used to rate and evaluate the financial profitability of each option. The IRR and NPV calculations are based on 12 years plant life and discount rate of 10% was used for NPV calculation. The annual cash flow is given by:

$$CF = C_{\text{revenue}} - C_{\text{material}} - C_{\text{transport}} - C_{\text{o\&m}} \quad (5.1)$$

It was assumed that the cash flow of the first year is the capital cost invested in the plant and that the first revenue will only be released in year two. Net present value The net present value (NVP) is the net value of all benefits (cash inflows) and costs (cash outflows) of the project, discounted back to the beginning of the investment. The benefits will essentially include the income from sale of charcoal briquettes.

The capital investment, the accumulated value of annual operation and maintenance costs constituting the payments. Thus the net present value is given by: Formula:

$$NPV = -C_0 + \sum_{i=1}^T \frac{C_i}{(1+r)^i} \quad (5.2)$$

Where,

C_0 = Initial investment Amount

C_i = Cash flow

T = No of years

If the NPV is greater than 0, the project is economically acceptable as it will bring profit to the investor. As seen from the given graph below the net benefit of the project was less than zero up to four years. Then the net benefit value increases and got positive sign at the fifth years of the project lifetime. It increases and the research found will get cumulative of more than 2,500,000 birr at 2025.

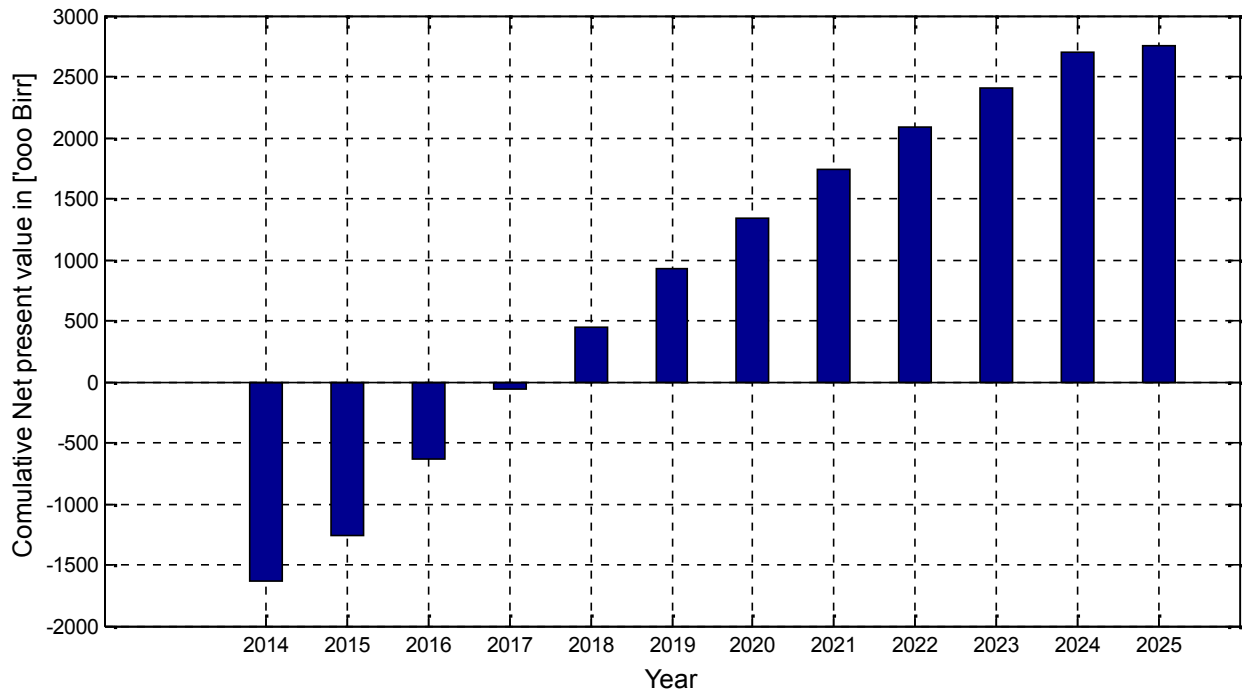


Figure 5-1: The NPV of the project

Internal Rate of Return

The internal rate of return (IRR): is defined as the discount rate at which the accumulated present value of all the costs becomes equal to that of the benefits. In other words, with IRR as the discount rate, the net present value of a project is zero. The IRR is often used by utilities or businesses in assessing investments and is a measure of profitability.

$$IRR = \text{Values of discount rate for NPVs to equal zero} \tag{5.3}$$

In this project the internal rate of return was 19%. The payback period:- of the investment can be found by equating Equation (5.2) to zero and solving for n. payback period is the period of time required to recoup an initial investment. It is simply 4 years. Economic Benefits the project can create employment opportunities for 21 persons. In addition to supplying the domestic needs, the use of this resource reduces 10,000 tons of CO₂/yr and 20,000 ton CH₄/per year. 5.4 Sensitivity Analysis The sensitivity of models to market fluctuations has not been investigated and poses a major risk to the feasibility of these scenarios. The market related variables identified for the sensitivity and risk analyses are accuracy of capital estimation and the selling price of fuel briquettes. For the purpose of the sensitivity analysis ,each of the variables were varied from-

10% and +25% from the base case scenario while the others were kept constant and the effect of these variations on the project IRR and NPV were plotted in Fig 5.2.

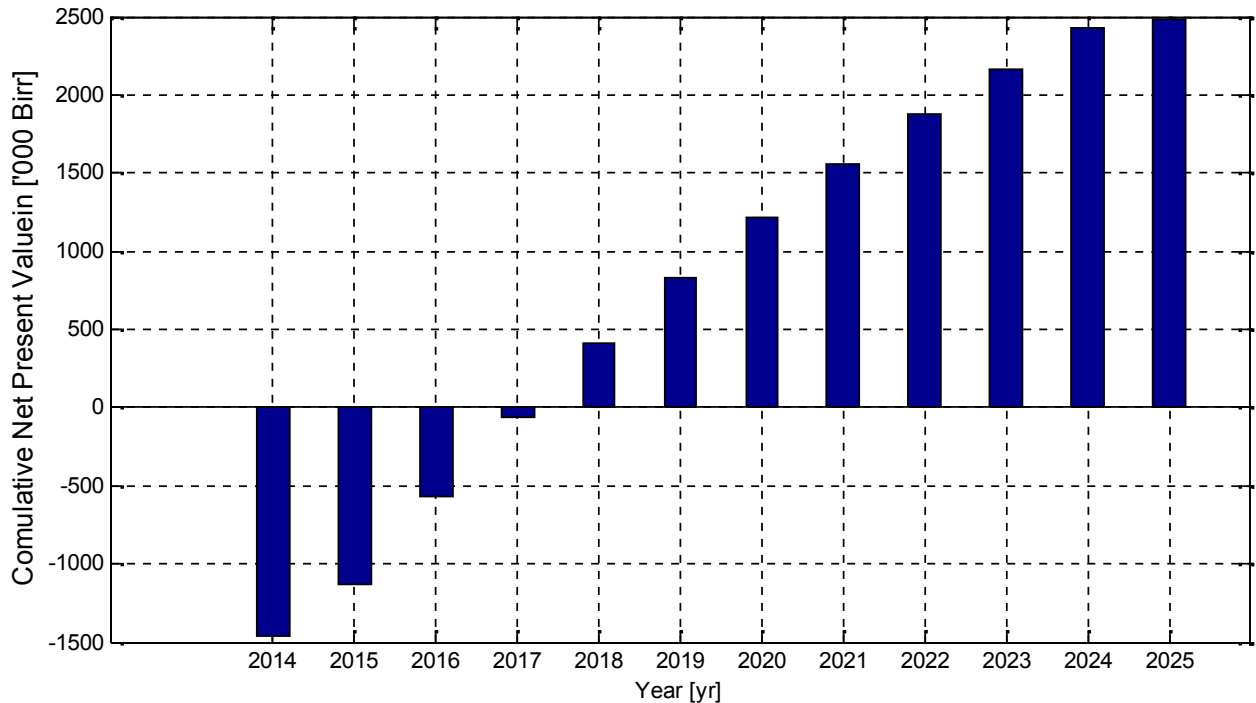


Figure 5-2: Project sensitivity analysis of briquetting plant as the interest rate changes to -10%

As seen from Fig 5.5, the sensitivity analyses indicate that the financial viability was found to be less sensitive to changes in initial investment costs and interest rates. A 10 percent decrease in investment costs and other cost would have no change on IRR (19% percent). Similarly, decreasing the investment and other costs by 10% in interest rate, the net present value would reduce from 2753,976 to 2478,578 birr.

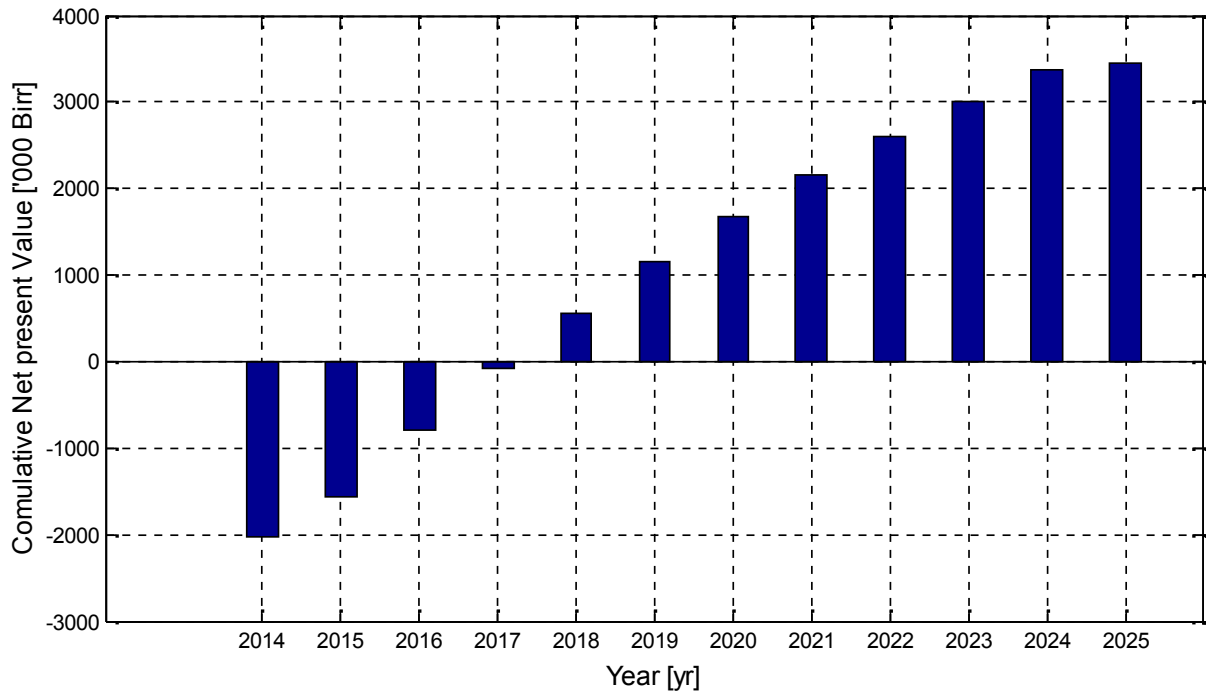


Figure 5-3: NPV sensitivity analysis of briquetting plant as the interest rate changes to 25%

The financial viability was relatively had no change on IRR as the price of everything changed into 25%. But the Net Present Value was increased from 2753,976 to 3442,465 Birr. The rate of return for the price remains the same, which is four years after the project started operating.

Chapter Six

Comparative Analysis of Biomass Charcoals Briquettes

6.1 Comparative Analysis Resource Available in Ethiopia

6.1.1 Analyses of Residues Estimated in Ethiopia

Jatropha pressed cake availability in Ethiopian can be calculated based on different scenarios. Three scenarios of Jatropha press cake availability were considered depending on the GEXSI report (GEXSI, 2008) on Jatropha cultivation in Ethiopia; Expert prediction and international study as scenario three. Scenario 1:- According to GXSI report, the area identified under Jatropha cultivation is 200ha, 125,000 ha for 2008 and 2015 year respectively. Assuming that 6 T/ha constant yield of seeds per ha to 2015, 75% of the seed remains as press cake after pressing the oil, 4kg of seed gives 1L of oil and the 3Kg remains as press cake. The press cake is 100% available for fuel briquettes.

Table 6-1: Potential of the Jatropha press cake in Ethiopia based on GXSI 2008 study

Year	Area of Jatropha Cultivated(ha)	Amount of Jatropha seed available T/ha	Amount of press Cake Available *Tones	No Briquettes Factory Predicted
2008	200	6	900	-
2015	125,000	6	562500	112.5

NB one briquettes factor consumes annual consumption of 5000 tons of raw material.

Scenario 2:- “INSIGHTS INTO JATROPHA PROJECTS WORLDWIDE” project 2011 survey report. According this report, in Ethiopia three projects were active and 20,000 hectare land cultivated. Based on this data, the estimated total availability of Jatropha press cake after de-oiled were 90,000 tones/year, considering 5000ton/year consumption of a given charcoal briquette plant. The total briquette plant was 18. See the figure below

Table 6-2: Potentials of the jatropha press cake in Ethiopia based on 2011 global study

Year	Area under Jatropha Cultivated (ha)	Amount of Jatropha seed available ton/ha	Amount of press cake available*Tone	No Briquette Factory
2011	20,000	6	90000	18

Scenario 3: According to Fortune Ethiopian newspaper published Oct, 2012. One Jatropha processing unit was erected in Bati, Amhara regional, state, Ethiopia with 300litter oil per day. According to Stelyus L. Mkoma [47], the estimated annual jatropha press cake was available using formula $4\text{kg press cake}=1\text{liter of oil and }3\text{kg of jatropha press cake}$. Then if the capacity of the machine was $300\text{Liter/day} \times 3 = 900 \text{ kg/day}$ press cake will be available. Taking 250 working days/ year for the plant, the potential will be 226,800kg/year or 226.8ton/year. Other companies like Artif Alternative Energy PLC in 2012 have planted for extracted 3,000 liter oil/day in SNNP. Calculating using the same formula, the total availability was 2268ton/year. African power Initiative of Biodiesels Company, in 2012 has constructed that extract 2000 liter of jatropha oil per day in Mekelle, a capital of Tigray regional state. Using the above formula, the total availability of the jatropha press cake was 1512ton/year. See the total availability in the table below.

Table 6-3: Total availability of jatropha press cake based on ministry of water and energy experts

Company Name	Estimated Press Cake Availability	Comment
Bati,	226.8 Ton/Yr	Already Have
Artif Alternative Energy Plc	2268 Ton/Yr	Not Yet Available
African Power Initiative	1512 Ton/Yr	Not Yet Available

Comparative Study Resources Assessment with other resource

Based on the general formula (3.7), the amount of residue available will be found in the Table 6.4 below. The data were from 2003 E.C Ethiopian statically agency censuses survey.

Table 6-4: Mean production of large and medium scale commercial farms [source: CSA, 2003

Biomass type	Mean production	Residue Ratio	Residue *Tone/Yr	No Briquettes Factory Proposed
Agricultural residue	5,969,085.92	7.8	4,655,887.00	931
Cotton residue	798,305.91	2.755	219933.27	44
Coffee residue	778,424.02	1.41	109757.78	21
Bamboo residue	1,000,000	--	1,000,000	200

Source: - FDRE central statistical agency, large and medium scale commercial farms sample survey 2010/11(2003 E.C).

Agricultural residues consist of Barley, Wheat, Maize, Sorghum and rice husk. Taking the medium commercial briquette factory with total consumption rate of 5000 tones/year, As seen from Table 6.3, if out of the total availability of agricultural residue, the country plans to use 1/3 utilizing for briquette factory, then there will be 310 briquette factory throughout the country. Based on the estimation of this research ,if all cotton stalk residue were used for charcoal briquettes production, then there will be a total of 44 briquette factory will be throughout the country. If the country planes use all coffee residues for making charcoal briquettes, then there will be 21 briquette factories throughout the country. From the available Bamboo residue, if the country planes use the entire bamboo residue, there will be 200 briquette factories in the country. Each estimated factory has a production capacity of 1300ton of charcoal briquettes each year. Then, the total availability of charcoal briquettes and substitute wood charcoal are compared in Table 6.5.

Table 6-5: Total projection of Briquettes plant and briquettes production capacity of the country

Waste Used	Expected Briquettes Plant	Expected Briquettes Production
Cotton Residue	44	44000ton/yr
Coffee	21	21000ton/yr
Bamboo	200	260000ton/yr
Composite Charcoal	-	-

Taking 1 briquette factory produce 1300 tons of briquettes per year.

6.1.2 Analysis Degree of Centralization:

Jatropha press cake found concentrated on the oil factory site. The factories are also concentrating on the farm area to reduce the production cost. The Jatropha plant is widely distributed in Ethiopia, existing in many low-lying areas of the country (North Shewa, Wello, Benishangul-Gumuz, Gambela, Welayita, Bale and others). Large volumes of residue are expected to be available from the bio-fuel processing industry over the coming years. Jatropha Press cake is used as fuel – in briquette form – in the same way as coffee husks. As seen from table 6.6, most biomass waste available throughout the country was agricultural residue. 5000 tones of these wastes can produce the moderate commercial charcoal briquette plant. Except Gambella, Afar and Somalia regions of Ethiopia can have a potential more than one charcoal

briquette plant. Afar, Amhara, SNNP and Gambella have the high potentials to produce charcoal from cotton stalks. Out of these regions, Afar had a high potential followed by SNNP and Gambella. Amahra has less potential even cannot produce 1 briquette factory. The high potential of coffee husk was found in SNNP and Oromiya. The other region in Ethiopia had a small amount like Amahar and Gambella. Where, Amahra, Oromiya, Benishangul-Gumuz and SNNP had high potential of bamboo residue. The most potential bamboo residue was found in Benishangul-Gumuz with 640,506tones/yr. followed by Oromiay with 275386.2tones/yr then SNNP with 65646.93 and Amahra with18460.01tones/yr.

Table 6-6: Location and available resource in Ethiopia

Region	Agricultural Residue Tone	Cotton Stalk Tone	Coffee Husk Tones	Bamboo Residue	Jatroph a
Tigray	157780.5	-	-	-	58,500
Forecast Briquettes plant	31	-	-	-	19
Afar	3008.318	90992.6	-	-	-
Forecast Briquettes plant	-	18	-	-	-
Amhara	219460.2	1599.005	72.51	18460.01	3978
Forecast Briquettes plant	22	-	-	3.6	-
Oromiya	522402.1	-	95286.54	275386.2	225000
Forecast Briquettes plant	104	-	19	55	45
Somalia	2790.358	-	-	-	-
Forecast Briquettes plant	-	-	-	-	-
Benishangul-Gumuz	118432.1	16.	-	640506.8	967500
Forecast Briquettes plant	23	-	-	125	193
S.N.N.P.R	121756.8	16049.82	153337	65646.93	4500
Forecast Briquettes plant	24	3	30	128	-
Gambella	2005.47	7625.532	692.05	-	-
Forecast Briquettes plant	-	1	-	-	-

Source CSA 2003 medium and large farm

Jatropha press cake was not available up to now, but after some years, the jatropha press cake will be available.

6.1.3 Analyses Clarity of Ownership:

In this study used Commercial Farms residue. And commercial farms : - “this sub-sector refers to the farms that include state and private commercial farms mainly established for the purpose of profit making by selling agricultural products at local markets and/or abroad”[48]. Cotton, coffee, agricultural and Jatropha farms in Ethiopia are commonly owned and operated by government, private companies and non-governmental institutions, such as private individual investors, share holders, religious and non- religious institutions. These wastes are disposed freely or sold for fuel or used for animal feeding for extra revenue. If charcoal briquettes are used, extra money can be made.

6.1.4 Analysis of Absence of Annual or Seasonal Variations in Supply:

All the residues were collected from the commercial farms during Meher season (Dec-March).

6.1.5 Analyses of Absence of Pre-existing or Compete Uses:

The biomass in this study was used for cooking, animal feeding and burned on the field [49].see the summary in table 6.7 below. In Ethiopia, Jatropha was a new material and no work has been done with it up to now. One factory located in bati, Amahra Regional State, was in the process to use it, but until now no work was done using the cake

Table 6-7: Pre existing use of biomass waste in Ethiopia

List of Waste	Pre-Existing or Competing Uses	Reference
Jatropha press cake	No use before	[-]
Agricultural Residue	Animal Fodder, fire-wood	[49]
Cotton stalk	no use before	[7]
Coffee residue	Field-burning and deposing	[5]
bamboo	different use but fast growth	[5]

Agricultural residue: Wheat straw, Maize straw, Sorghum, Rice husk

6.2 Comparative Analysis Physic-Chemical Property of Charcoal Briquettes:

6.2.1 Physical Property Analysis

The physical property of composite charcoal briquettes were analyses as follow.

Table 6-8: Physical property of composite charcoal

Property	Strength	Density
Values	10.19 kg/cm ²	1,050 kg/m ³

The strength pressure of composite charcoal briquettes 10.197kg/cm² was higher than the one rice husk (7.59 kg/cm²-8.99 kg/cm²) [50]. The particle size was < 75µm and had a density of 10.197kg/cm³. When comparing with other countries standard the composite charcoal briquettes found good value based on standards of Sweden (SS 18 71 20), America(PFI) and Germany(DIN 51371) but it was not good for standards like Austria (ONORM M 7135) and France (ITEBE) see Table 6.9 below for further.

Acacia spp. Wood charcoal in Ethiopia produced locally and when the density compared with biomass briquettes it found in the same limit with the Sweden (SS 18 71 20) Standard America (PFI) Standard Germany (DIN 51371) so briquettes made using this standard can substitute wood charcoal in Ethiopia. Hence our finding, composite charcoal briquettes lying in this standard limit, composite charcoal briquettes can substitute acacia charcoal in Ethiopia.

Table 6-9: The comparison of bulk density of acacia charcoal with briquettes from some countries

Sources	Bulk density kg/m ³
Standard Austria (ONORM M 7135)	> 1,120
Sweden (SS 18 71 20)	>600
Standard America (PFI)	> 640
Standard Germany (DIN 51371)	1,000-1,400
Standard France (ITEBE)	> 1,150
Ethiopian Acacia spp. Charcoal	1,100

6.2.2 Proximate Characterizing Analysis of Composite Briquettes

Using ASTM standard procedures, the composite briquettes proximate analysis was done and put in Table 6.10 below. The composite charcoal briquettes were made by 25% of carbonized agricultural residue (barley and wheat straw) and 75 % Jatropha press cake. Based on the optimized result, 18% clay binder and 82% Jatropha press cake plus agricultural residue were used. The pressure was at 4MPa for 3 minutes holding time.

Table 6-10: Proximate properties of composite charcoal briquettes

Property	Moisture %	Volatile Matter%	Ash%	Fixed Carbon%
Composite Charcoal	4.25	11.55	16	68.2

Composite charcoal briquettes were found to have a moisture content of < 10% as recommended scale 5-10% moisture content. Volatile matter of composite charcoal briquettes was 11.55% which, is in the recommended scale <30%. The ash content of the composite charcoal briquettes was 16% which is in the range of 10-30%. The fixed carbon of composite charcoal briquettes were 68.2%.

i. Comparing Proximate Property of Composite Briquettes with Wood Charcoal

Proximate property consists of moisture content, volatile matter, fixed carbon and ash content. These Proximate properties, was compared with wood charcoal and other biomass charcoal briquettes. The finding was plotted here with.

ii. Comparing Analyses of Moisture content of different charcoal briquettes

The moisture content has an influence on net calorific value, combustion efficiency, and combustion temperature and moisture content equilibrium with the ambient moisture content that affects storage conditions [51]. It is influenced by treatment, material composition, weight of the material and drying process. The comparison result was put in the following graph.

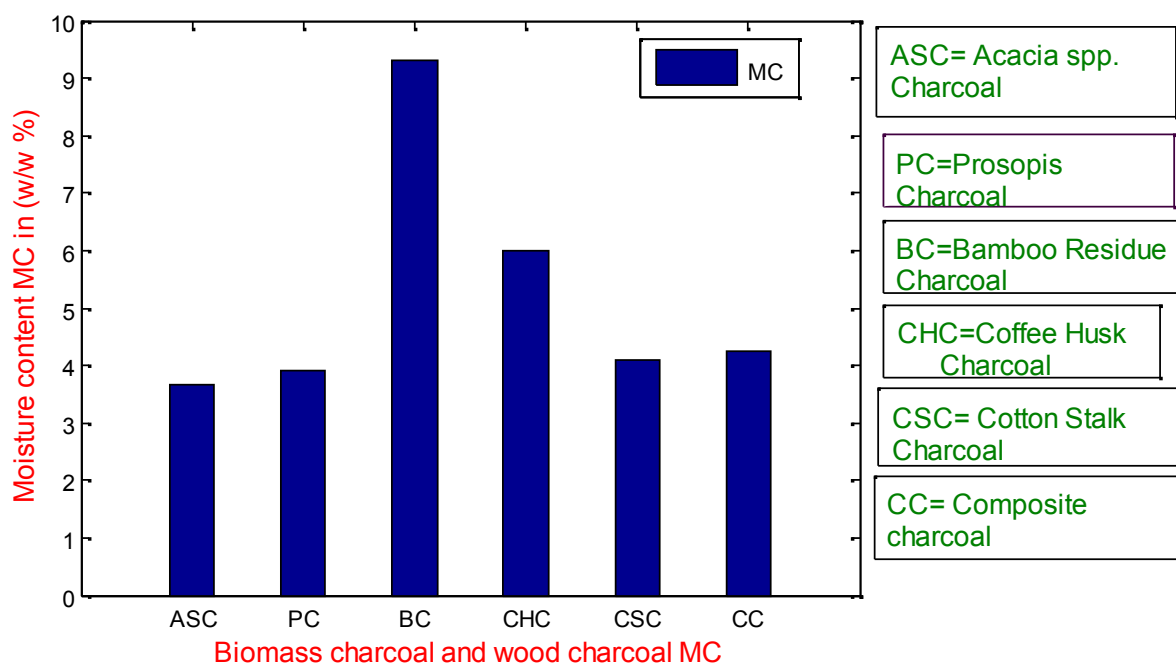


Figure 6-1: Comparison of moisture content of composite charcoal with wood charcoal and other biomass charcoal in Ethiopia

The moisture content of the charcoal produced from Acacia spp. Charcoal was then lowest with a moisture content of 3.67%, while biomass charcoal produced from Bamboo residue was the highest with a moisture content of 9.31 %. value of moisture content was, which was the, as for moisture contents of charcoal produced from prosopis, coffee husk, cotton stalk and composite (JPC and AR) residue 3.9%, 6.0%, 4.1% and 4.25%, respectively as shown in Figure 6.1 above. Most charcoal consumption in Ethiopia was charcoal from Acacia spp. and had low moisture content. Comparing charcoal briquettes, all biomass charcoals had higher moisture content than wood charcoal. Reducing the moisture content need some energy in Ethiopia drying cost is simple as the country located in the tropic and had abundant space for drying. All charcoal briquettes produced in Ethiopia were below lying in the standard limit of many countries, see Table 6.11. The charcoal briquettes can substitute acacia spp. charcoal but some cost incurred for drying cost.

Table 6-11: Moisture content standard of briquettes produced from different countries

Sources	Moisture Content (%)
Austria (ONORM M 7135)	<10
Germany (DIN 51371)	<12
Sweden (SS 18 71 70)	10
Italy (CTI – R 04/5)	10
France	15

iii. Comparing Analyses of Volatile Matters of Different Charcoal Briquettes

Volatile matters in wood charcoal of acacia spp. and prosopis charcoal has significantly high value with 22.9% and 25.9%, respectively, while volatile matters of the charcoal produced from biomass briquettes have lower value than wood charcoal. Bamboo, Coffee and cotton stalk were also different at 15.03%, 23% and 17.2%. The lowest volatile matter was 11.5%, which of composite charcoal briquette. The volatile matter of the biomass charcoal and wood charcoal was as shown in Figure 6.2 below.

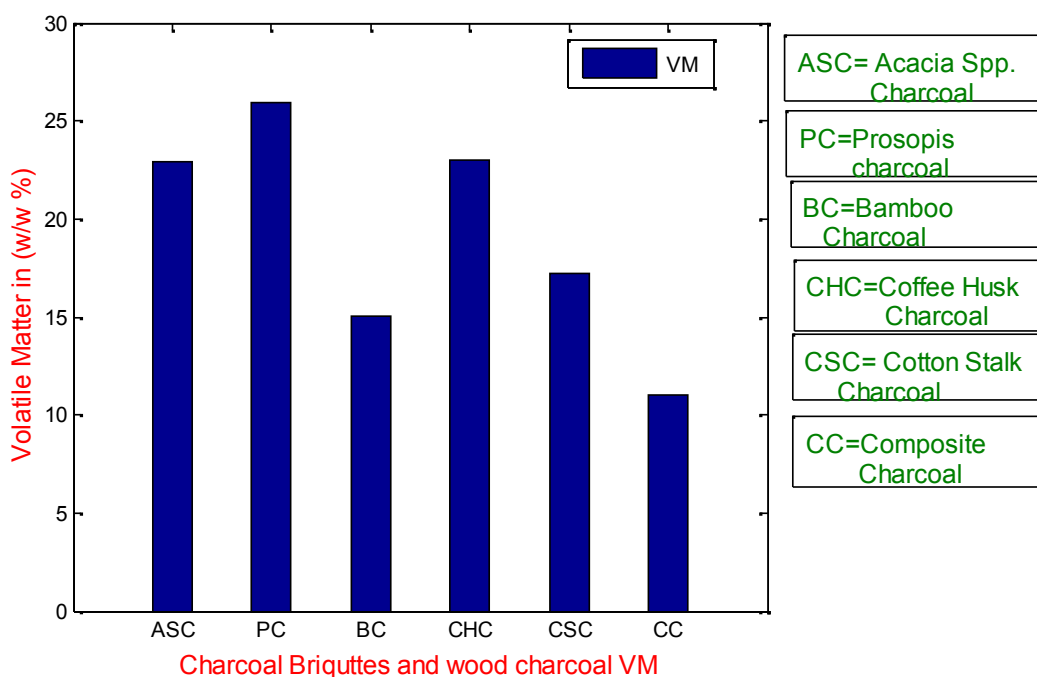


Figure 6-2: Comparing composite charcoal briquettes with other charcoal fuel found in Ethiopia Based on FAO criteria both wood charcoals used in Ethiopia have the desired value between 20 to 25% [52]. In this study both wood charcoal had higher volatile matter than biomass charcoal briquettes. In addition, the high value of volatile charcoal tends to be stronger, heavier, harder

and easier for the ignition than low volatile charcoal. Therefore, high volatile charcoal is easier to ignite, but may burn with smoky flame while low volatile charcoal is difficult to ignite and burns with less smoke. Consequently, high volatile charcoal is preferable for domestic charcoals [50]. The volatile matter content of composite charcoal briquettes were as shown below 11.03% Figure 6.2. As we compare the volatile mater with other biomass charcoal and wood charcoal the composite charcoal had less volatile mater. As [50] reports the volatile matter and the combustion and smoke generation had vice versa related. Comparing Composite (JPC and AR) charcoal, Cotton stalk charcoal briquettes and Bamboo charcoal had less volatile matter than wood charcoal. The overall meaning of less volatile is having less smoke and highly combustion rate.

iv. Comparing Analyses of Ash content of different charcoal briquettes

Cotton stalk Biomass charcoal had 20.3 % of ash content, which was significantly different from other biomass charcoal and wood charcoal. The proportion of ash content in bamboo, coffee husk and composite charcoal had only 14.8%, 13.1% and 16%, respectively, which is lower than those of other wood charcoals from Acacia spp., prosopis charcoal with 3.69% and 3.5% respectively as shown in figure 6.3.

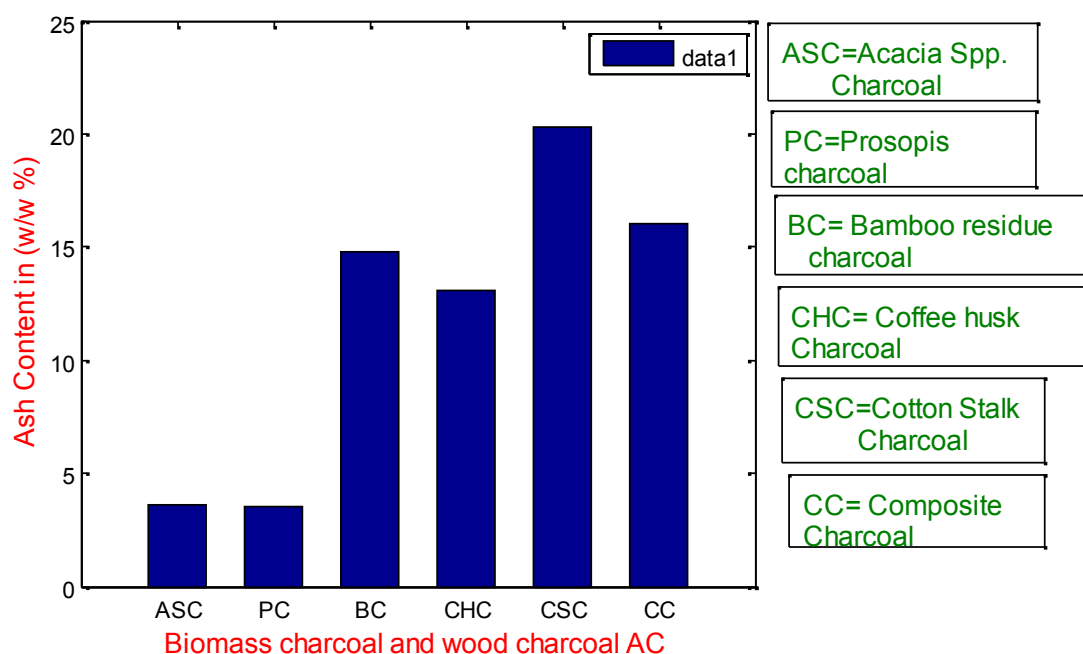


Figure 6-3: Comparing composite charcoal briquettes with other charcoal fuel found in Ethiopia

According to FAO (1987) concerned that the good quality charcoal should have typically the ash content ranged from 3 to 4% and when we compared it with our Ethiopian wood charcoal they have values between the ranges. FAO (1985) identified that the ash content of the briquette charcoal may have high ash content 5-10% none of Ethiopia briquettes have these values. Therefore, the result of the ash content of briquette charcoal in this research indicates some work should to do for improving the ash content. However, briquette charcoal still contains the high ash content compared to other wood charcoals within this investigation. The ash contents of biomass charcoal of bamboo, cotton stalk, coffee husk and composite in this study range from 13.1% to 20.3% (w/w). The ash content of this charcoal did not meet the standards of Austria, Germany, America, and France [50]. But it is similar to rice husk briquettes which range from 15.24-20.00% [48]. The research found that Ethiopian charcoal briquettes Ash content had greater ash content than the acacia charcoal. It seems it didn't replace charcoal, but if we compare the ash content of different briquettes made in different countries. As seen from fig below. If use machines, high technology machines without binder we can have lower Ash content.

Table 6-12: Comparison of ash content of acacia charcoal with briquettes from some countries

Country	Ash Content
Austria (ONORM M 7135)	<0.50
Germany (DIN 51371)	<1.50
America	<2.00
France	<6.00
Ethiopian Acacia Charcoal	3.64

v. Comparing Analyses of Fixed Carbon of different charcoal briquettes

Fixed carbon in the wood charcoal was 69.78%, which was the greatest proportion compared to the charcoal produced from different briquettes charcoal and wood charcoal. The charcoal produced from Bamboo, coffee husk and cotton stalk were not significantly different of fixed carbon value 60.85%, 63.9% and 58.4%, respectively, and the lowest value of fixed carbon was 58.4%, which was the charcoal produced from cotton stalk shown in figure 6.4.

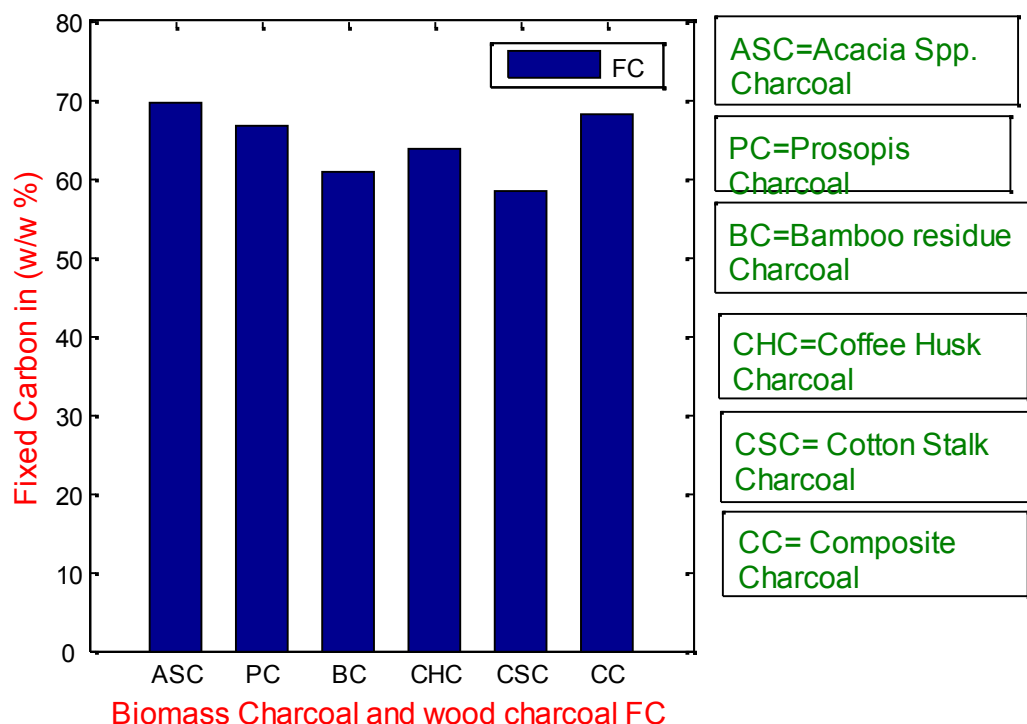


Figure 6-4: Comparing FC of composite charcoal briquettes, wood charcoal and other fuel found in Ethiopia

According to the criteria of FAO, both wood charcoals in Ethiopia pass the range. The fixed carbon of charcoal ranges from approximately 50% to a high of around 95% (lowest to highest) (6.13). Thus, the charcoal mainly contains fixed carbons. FAO (1985) recommends that 80.5% of charcoal contain fixed carbon for domestic use while 86.7% for industrial use [53] But none of the charcoal studied by this study had this value (80.5- 86.7%). On the other hand, the quality smokeless domestic wood charcoal has been specified to contain 75% of fixed carbon or more [48]. Researches by Hindi 1994, Erlinda and Dionco-Adetayo, 2001 both pointed out that fixed carbon is related to the carbonization time and temperature so; the differences obtained in this research were due to carbonization time and temperature. The higher the fixed carbon contents of briquettes, the better the combustion [53]. So, among the charcoal briquettes, coffee husk has the highest fixed carbon, hence has better combustion property.

6.3 Comparative Analysis of Calorific Value to Different Charcoal Briquettes

Gross calorific value differences were found between charcoals and biomass briquettes. Acacia spp. and prosopis wood charcoals had the gross calorific value of 32573.31 KJ/Kg and 26192.62 KJ/Kg respectively. While briquette charcoal produced from bamboo, coffee husk, cotton stalk and composite had values of 29135.94KJ/Kg, 11710.48KJ/Kg, 19209.04KJ/Kg and 23224.18 KJ/Kg respectively as shown in figure 6.5.

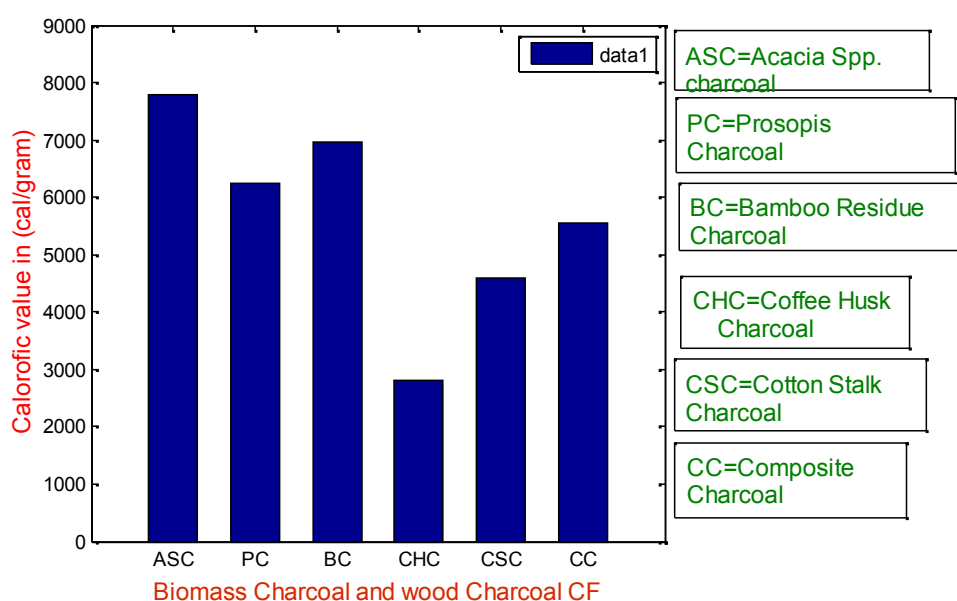


Figure 6-5: Comparing HHV of composite charcoal briquettes with other charcoal fuel found in Ethiopia

Bamboo Briquette charcoal had the higher gross calorific value compared to the charcoal produced from prosopis, while it is lower than Charcoal from Acacia spp. The highest gross calorific value from all biomass charcoal briquettes was bamboo charcoal with 29135.94KJ/Kg. Significant differences of gross calorific values of the charcoal produce among different wood species might be due to the difference in the age of the wood species used for charcoal production. Charcoal from acacia spp. had the highest gross calorific value but it was too, sparking when combusted in cooking stove. It also had the shortest burning time compared to other prosopis wood charcoals and briquette charcoal. Even, bamboo briquette charcoal had higher gross calorific value compared to prosopis wood charcoals.

Table 6-13: Comparison of the caloric value of acacia spp. charcoal with bio-pellet from some countries

Sources	Caloric Value (KJ/kg)
Standard Austria (ONORM M 7135)	18000.31
Standard Sweden (SS 18 71 70)	16900.44
Standard Germany (DIN 51371)	17500.41– 19500.44
Standard Italy(CTI – R 04/5)	16900.44
Ethiopian Acacia spp. charcoal	32573.30

The gross calorific value is an important parameter to determine the fuel quality. As the gross calorific value of charcoal from the acacia spp. is compared to world standards, it was found to have greater gross calorific value than other briquettes. Calorific value property depends on the nature of the material. It is affected by moisture content and ash content and is closely related to the level of fixed carbon [48].

6.4 Comparative Analysis of Combustion of Charcoal Briquettes

The analysis was done by using Water Boiling Test (WBO) method. The parameters were the consumption rate and the combustion efficiency of composite charcoal briquettes. Consumption Rate: is the amount of briquette mass that is progressively burned in a unit of time. The higher the bulk density of the material, the slower the rate of combustion is. The consumption rate of composite briquettes was measured for two replications so that the results were in an average consumption rate of the composite briquettes as shown below (Table 6.10).

Table 6-14 Consumption rate of charcoal briquettes

Repetition	Boiling time of 1L of water (minute)	Briquettes mass that used (g)	Consumption rate Kg/hours
1	9.008	120	0.799
2	8.773	110	0.821
Average	8.889	115	0.81

The average boiling time of a liter of water was 8.889 minutes, the burned composite charcoal briquettes was 115 grams and the fire color that formed during the combustion was red. The black, combustion smoke has been just little in intensity and produced at the initial stage of the combustion process. The consumption rate was measured twice. The result of this study showed

that the average consumption rate of composite charcoal briquettes were 0.81 kg/hour that was lower than that of Rice Husk 1.76 kg/hour [48] and palm shell briquettes 1.29kg/hr but higher than that of raw jatropha cake 0.63 kg/hour [48].

6.5 Comparing Analysis Based on Environmental Emission

6.5.1 Methane Emission Analyses

Baseline scenario was calculated based on the efficiency of the carbonization. It had an efficiency of 15% and was calculated based by using formula 6.15. The graph is shown below

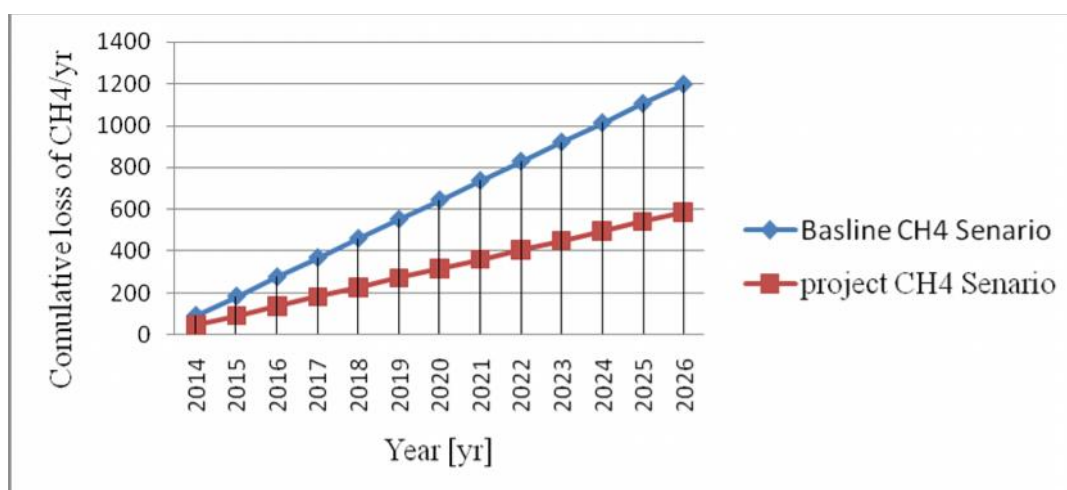


Figure 6-6: Comparative of methane emission in both baseline and project scenario

For the project scenario, the efficiency of carbonization was 30%. The improved kiln currently has an efficiency of 30%. The comparative methane emission of the project scenario and the baseline scenario are as shown above in figure 6-6. As seen from the graph, business methane emission continues as it is, methane release will be 1200tonCH₄/yr for a given production of 1300tonnes of charcoal. Taking the country's total charcoal consumption, the country will emit a total of CH₄, but if an improved carbonization process is implemented, the total methane emission will be reduced by half.

6.5.2 CO₂ Emission Analyses

The project baseline uses 12% efficacy to produce the same demand, 1300 tones for the community. But if the same amount of charcoal produced using improved carbonization methods. The efficiency of the improved carbonization was 30-45% depends on the biomass resource [56]. The CO₂ emission is analyzed as shown below.

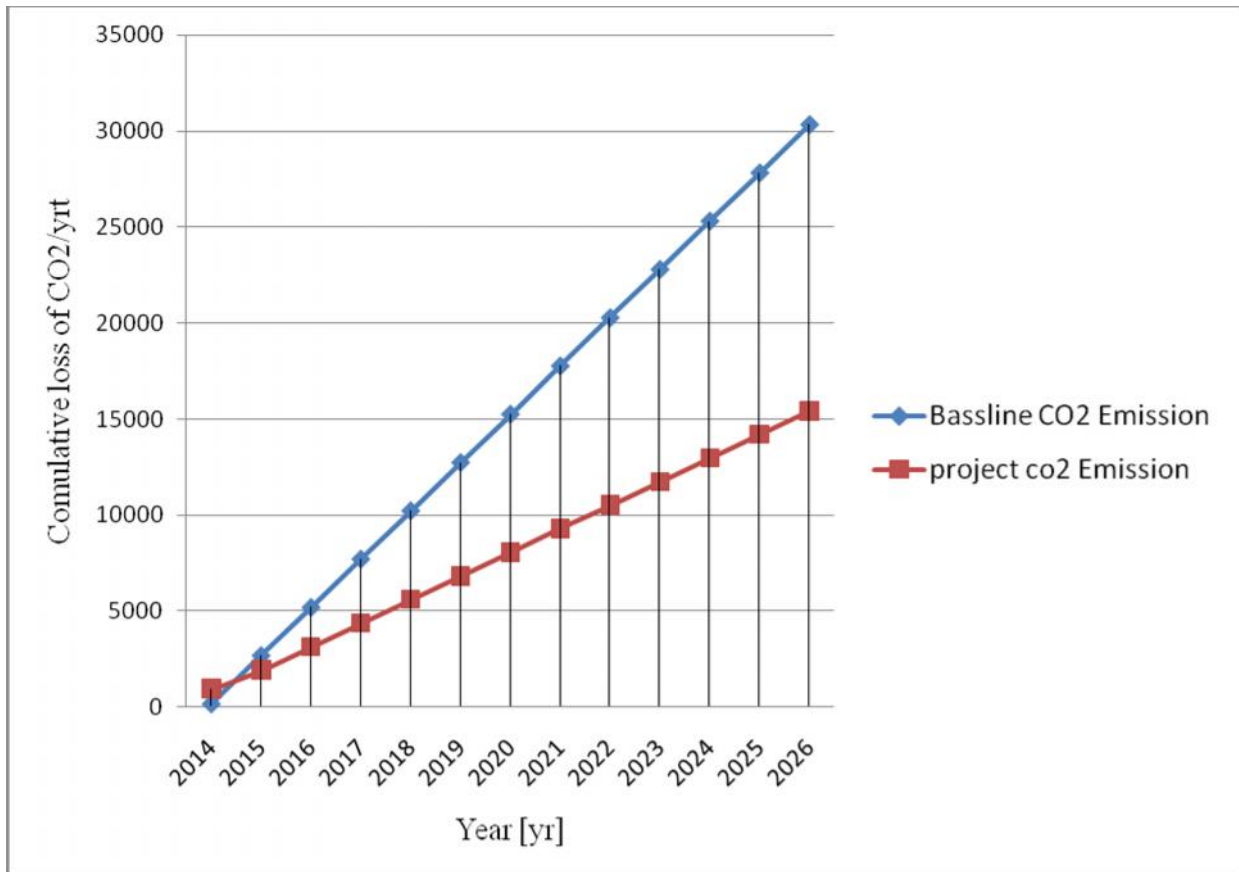


Figure 6-7: CO₂ Emission from both baseline and project scenario

As seen from the graph, if traditional method is used to produce 1300 tons of charcoal, cumulative 30000 tones of co₂ will be emitted. But for a given tone of charcoal production using improved kiln the, of co₂ will be saved.

Conclusion and Recommendation

Bamboo residue, cotton stalk, coffee husk, agricultural residue were among the most residue available in Ethiopia. Currently people used these wastes for cooking, but if they are used for charcoal production it will have a great advantage. In this research it was found that fixed carbon and moisture content of carbonized agricultural residue and the jatropha press cake had a higher value than that of un-carbonized ones.

Jatropha press cake will have higher availability in the coming years compared to the current situation. It can also be concluded that preparing composite charcoal is more beneficial for limited resources like jatropha press cake in Ethiopia. For manufacturing composite charcoal briquettes the optimal point was found at pressure=45bars dwell time, 3minute and clay binder 18.27%.

Based on the three scenarios of jatropha press cake availability, almost all show there will be a huge amount of resource in the up-coming years (after 2014). The strength and density of the composite charcoal were found to conform to American and Sweden standards. The moisture content, volatile matter, ash content and the fixed carbon value of the composite charcoal were 4.25%,11.55%,16%,68.2% respectively. Charcoal produced from these wastes had relatively similar value with Acacia wood charcoal, the most efficient wood charcoal in Ethiopia. The greater difference was on ash content. The ash content of charcoal briquettes from the above wastes had a higher value than acacia wood charcoal. But charcoal produced from this waste can substitute wood charcoal. The combustion of composite charcoal briquettes had higher value than bare jatropha press cake briquettes.

CH₄ and CO₂ were the most dominate particle which emitted during the production of charcoal. But during the production of charcoal briquettes there was an improvement in the kiln design. The emission due to carbonization could be reduced by half if the improved carbonization method was implemented.

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