

Title of the project:
**Assessing the Potential of Coffee Parchment for
its Effective Utilization as Alternative Biomass
Fuel in Cement Industry**



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Coffee parchment



CP-pellet

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Abstract

Many of the developing countries produce huge quantities of agro-processing residues with an interesting potential for biomass energy production provided that the higher moisture content and lower density of the biomass is managed to improve the combustion and handling problems. But they were used inefficiently causing extensive pollution to the environment. Moreover, the methods for effective utilization of the wasted resources specifically coffee parchment were not well developed. Therefore, this study were carried out to investigate potential of wasted resource, specifically coffee parchment to produce energy either alternatively used or supplement the current energy demand of cement industry. This was investigated by: estimating quantity of coffee parchment generated from different wet coffee processing facility, establishing optimum route for collection, and, characterizing the quality and type of raw biomass fuel and upgrading the fuel so as to enhance transportation, handling and utilization with optimum efficiency of kiln and without degrading the quality of clinker produced. Related to this distance between wastes sources were identified according to their position identified using GPS and finally with the help of the Arc-GIS software to choose optimized collection routes; different instruments and ASTM standard procedures were used for chemical, proximate and ultimate analysis of raw coffee parchment and pellet. Moreover, heating value, Ash oxide analyses and trace metal analysis were examined in order to investigate combustion properties and quality of the product to be used in clinker production and the results were compared. The analysis result showed the quantity of coffee parchment generated were estimated to be in the range of 10,583.5 to 12,460.5 tonnes per year, however it has been used inefficiently and irregularly by the local population who utilize the loose parchment as a cooking fuel. It was found within a radius that covers a total distance of 41.6 km. Ultimate analysis result confirmed higher C (45.5%) and H(6.5%) and lower N (0.4%) and S (0.1%) contents in the coffee pellet as compared to most commonly used biomass fuel and meet the standards specified for non-wood pellets, which implies that it has suitable property for alternative fuel use. Moreover, moisture content (11.2%) and ash content(5.97%) of the pellet is less than the amount specified in most biomass fuel and in accordance with ISO 17225-6 standard for non-wood pellets sated to use as alternative fuel and meets requirements of cement industry for thermal utilization. The observed lower fixed carbon contents (8.6%) in the coffee parchment pellet than many other woody and non-woody biomass might be related to differences in the chemical composition of the used biomass as well as the operations conditions. Improved gross heating value (HHV) from 18.56 and 27.95 MJ/kg and Ash oxides contents as a result of pelletizing of coffee parchment makes coffee parchment to have comparable values to common fuel woods and coal. This makes coffee parchment pellet suitable to be used as alternative energy source to be used in the clinker sintering zone for proper kiln operation and satisfactory quality of the clinker product up on careful design of the fuels ash and the raw materials. Overall analysis result confirmed that laboratory prepared coffee parchment pellet can be a promising source of alternative fuel and its effective utilization may reduce the raw material demand in cement industry in addition to its contribution to supplement fuel demand which rely on imported coal.

Keywords: pellets, coffee parchment, biomass, biofuel.

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Abbreviations and Acronyms

ASTM	American Standard test method
ASTU	Adama Science and Technology University
Cal/g	Calorie per gram
CEN	European Committee for Standardization
CRGE	Climate-Resilient Green Economy
CSI	Cement Sustainability Initiative (CSI)
EC	European Commission
ESMAP	Energy Sector Management Assistance Progra
GHG's	Green House Gases
GPS	Ground Positioning System
HHV	Higher Heating Value
ICO	International Coffee Organization
ICP-OES	Inductively coupled plasma optical emission spectroscopy
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LHV	Lower Heating Value
MJ/kg	Mega Joule per Kilogram
PFI	Pellet Fuel Institute
RDF	Residue Dried Fuel
VOCs	Volatile Organic Carbons

1. Introduction

1.1. Background and Justification

Cement is considered as one of the most important building materials around the world. Today, the world cement market represents over two billion tons and is growing by 5% every year. Similarly Cement industry is flourishing in Ethiopia due to the rapid economic growth, increase in population and the change in living style, and the availability of raw material in the region. Cement production naturally consumes non-renewable raw materials: limestone and clay which are the basic constituents of cement, and it is an energy-intensive process consuming thermal energy of the order of 3.3 GJ/tonne of clinker produced. Electrical energy consumption is about 90 – 120 kWh/tonne of cement (Giddings, et al, 2000; European Commission [EC], 2001). The energy (principally coal and heavy fuel oils) consumed by the Cement industry, is estimated at about 2% of the global primary energy consumption and contributes 5% of global anthropogenic CO₂ emissions (Hendriks et al., 1998; Murray, & Price, 2008). Moreover, cement production releases dust, SO₂, NO_x, CO and VOCs in to the environment during the heating process in the kiln (by the chemical reaction of the materials and by burning the fossil fuels necessary to heat the kiln), and their associated quarries (Battelle, 2002). As a result, the viability and prospects of future existence let alone growth of cement industry depend on adopting a responsible approach to this challenge.

Apply the principles of industrial ecology to this challenge seek development/use of alternative fuels, such as using waste oil, sludge or biomass from vehicles, manufacturing and processing industry either on their own or in various combinations to partially/fully substitute fossil fuels used to heat its kilns. This optimized organization of industrial flows has a number of benefits: above all contributes for considerable energy cost reduction, have significant ecological benefits of conserving non-renewable resources, reducing net CO₂ emissions per ton of cement, it encourages the optimization of the use of resources and influences the amount of waste produced, and it encourages the creation of new utilization networks by favoring the development of recycling. Moreover, using waste products as fuel in cement industry of Ethiopia is a radical solution for the elimination or destruction of certain waste products which otherwise would landfilled or dumped in to different water bodies, has health risks, and pollute the

environment due to inadequate waste processing systems in most cities. All this help us to meet sustainability in the country development (Yisehak Seboka, 2009).

The level of alternative fuel use is widely variable between countries. Most European countries used Paper waste, Paper sludge, spent solvents, Sewage sludge, Rubber Waste, woods and Plastics in their cement industry and these alternative fuels provided about 18% of the thermal energy consumption in the European Cement industry, substituting/saving approximately 5 million tonnes of coal per year (CEMBUREAU, 2013). In Ethiopia, even though these wastes is a major potential source of social and environmental problems in the different cities, resulting from contaminant emitted as a result of improper waste management, and during processing of the original feedstock or operational problem in the manufacturing process. For instance, simple burning of biomass waste contaminated with chlorinated solvents (produced in a shop or garage) would release contaminants such as dioxins, chlorinated hydrocarbons and heavy metals into the environment that are more toxic than the original feedstock, and may be a concern for slugging and corrosion in the cement kiln. So far nothing has been taken to make use of these wastes as alternative fuel in Ethiopia Cement industry. On the other hand the government of Ethiopia has promoted the production and the use of renewable energy sources with purposes to reduce the country's importation fuel oil, enhance the energy security of the country. In relation to this ministry of industry for energy set the goals of creating favorable climate through promoting, facilitating and encouraging specific replacement and energy improvement initiatives by cement companies and meet energy substitution target set by Ethiopia's Climate-Resilient Green Economy (CRGE) initiative. Accordingly the ministry put a target of substituting 20% of thermal energy requirement of cement industries with alternative energy from sources such as biomass and municipal wastes by 2020 and at least 30% at the end of 2025 to meet the stated goals.

Therefore, addressing concerns related to sustainability of the Cement industry, and environmental, social and economical concerns related to releases of wastes by employing as alternative fuel were investigated. The investigation in this project primarily focus on coffee parchment from wet coffee processing facility and includes establishing effective collection network, detail physicochemical characterization of the by-products and subsequent upgrading to improve the heating efficiency and in order to avoid negative effects on the final cement quality.

1.2.Objective of the study

General objective

The research project has a general objective of providing the scientific bases for efficient utilization of coffee parchment as biomass fuel in the cement industry. In detail, the planned research projects are the following specific objectives.

Specific Objectives

- I. Determine the amount of coffee parchment generated in Addis Ababa city and its effective collection route
- II. Proximate, ultimate, chemical and thermal properties characterization of coffee parchment to be used as alternative fuels:
- III. Pre-treatment of coffee parchment to meet the standards to be used as alternative energy source in the cement production.

1.3.Significance of the study:

With successful implementation of the project results:

- The energy costs, foreign currency (as the current energy source which is coal is imported from abroad), and dependability on fossil fuel resources of cement industry will be reduced which in turn help us to meet sustainability in the country development.
- efficient industrial waste management that led to reduction of wasted resources that goes to nearby water bodies and landfills will be achieved;
- Job opportunities will be created as individuals or group of peoples are expected to be involved in the collection, processing, and supply of produced alternative fuels to the end users
- Increased awareness on the concept of industrial ecology among different stakeholders will be achieved, so that the local government, industries, and policy makers can extend the new concept to develop their strategies to solve the existing industrial waste management problems, dependency on non-renewable resources, and inefficient use of resources.
- Global benefit would be achieved by reduction of greenhouse gas (GHG) emissions

- New fundamental knowledge about efficient use of wasted resources as alternative energy source will be obtained and used as a baseline data for further investigation.

2. Literature review

2.1. Cement production process

Cement is considered one of the most important building materials around the world. In 1995 the world production of cement was about 1420 million tonnes (CEMBUREAU, 1997). Cement production is an energy-intensive process consuming thermal energy of the order of 3.3 GJ/tonne of clinker produced, which accounts for 30 – 40 percent of production costs (Giddings et al., 2000; EC, 2001). Worldwide, coal is the predominant fuel burned in cement kilns. Cement production consumes approximately 120 kg of coal per tonne of cement. In the European Union about 25 million tonnes of coal is required annually by the Cembureau members to service the demand of cement in Europe. In 2005, the global cement industry consumed about 9 exajoules (EJ) of fuels and electricity for cement production (IEA, 2007, as cited in Murray & Price, 2008).

Cement production involves the heating, calcining and sintering of blended and ground raw materials, typically limestone (CaCO_3) and other materials containing calcium, silicon oxides, aluminium and iron oxides to form clinker. Clinker production takes place at material temperatures of about 1450°C in either rotary or shaft kilns. Carbon dioxide is released during the production of clinker. Specifically, CO_2 is released as a by-product during calcination, which occurs in the upper, cooler end of the kiln, or a precalciner, at temperatures of $600\text{-}900^\circ\text{C}$, and results in the conversion of carbonates to oxides. The limestone (calcium carbonate) decomposition process known as ‘calcination’ ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$) is virtually completed (approximately 95 percent) in the precalciner if 50 – 60 percent of the total fuel required for clinker production is added to this chamber (Taylor et al., 2006).

The clinker is then removed from the kiln to cool, ground to a fine powder, and mixed with a small fraction (about five percent) of gypsum to create the most common form of cement known as Portland cement.

2.2. Benefits of using alternative fuels in cement production

Cement producers worldwide are striving to lower their production costs. One effective method of achieving this end is the use of alternative fuels (Murray & Price, 2008). Use of low-grade alternative fuels such as waste coal, tyres, sewage sludge, and biomass fuels (such as wood products, agricultural wastes, etc.) in precalciners is a viable option because combustion in a precalciner vessel takes place at a lower temperature. In precalciners where kiln exhaust gases pass through, the NO_x emissions are much reduced due to re-burn reactions. There is an increased net global reduction in CO₂ emissions when waste is combusted in the cement kiln systems as opposed to dedicated incinerators, resulting in reduction in the CO₂ penalties. Since alternative fuels are often deemed cheaper than conventional fossil fuels, the possibility of a competitive edge is generated.

The use of alternative fuels in cement manufacture is also ecologically beneficial, for two reasons: the conservation of non-renewable resources, and the reduction of waste disposal requirements. The use of alternative fuels in European cement kilns saves fossil fuels equivalent to 2.5 million tonnes of coal per year (CEMBUREAU, 1999). The proportion of alternative fuels used in cement kiln systems between 1990 and 1998 in some European countries are as follows in order of importance: France 52.4 percent; Switzerland 25 percent; Great Britain 20 percent; Belgium 18 percent; Germany 15 percent; Czech Republic 9.7 percent, Italy 4.1 percent; Sweden 2 percent; Poland 1.4 percent; Portugal 1.3 percent and Spain 1 percent (Mokrzycki et al., 2003; Murray & Price, 2008).

The process of clinker production in kiln systems creates favorable conditions for use of alternative fuels. These include: high temperatures, long residence times, an oxidizing atmosphere, alkaline environment, ash retention in clinker, and high thermal inertia. These conditions ensure that the fuel's organic part is destroyed and the inorganic part, including heavy metals is trapped and combined in the product. The wastes used as alternative fuels in cement kilns would alternatively either have been landfilled or destroyed in dedicated incinerators with additional emissions as a consequence. Their use in cement kilns replaces fossil fuels and maximizes the recovery of energy. Employing alternative fuels in cement plants is an important element of a sound waste management policy. This practice promotes a vigorous and thriving materials recovery and recycling industry (CEMBUREAU, 1999; CSI, 2002).

2.3.Challenges of using alternative fuels in cement production

Alternative fuels used in cement manufacturing have different characteristics compared to the conventional fuels. Switching from conventional fuels to alternatives fuels presents several challenges that must be addressed in order to achieve successful application. Poor heat distribution, unstable precalciner operation, blockages in the preheater cyclones, buildups in the kiln riser ducts, higher SO₂, NO_x, and CO emissions, and dusty kilns are some of the major challenges (Smidth & Co., 2000).

The operation of cement kiln system is not only affected by the chemical composition of the main components of the raw meal but also the combustion and consequently the fuel used. The type of fuel used can introduce some material components which can interfere with the chemistry of the cement materials as well as affect the operation of the system. The use of a type of fuel is therefore subject to the constraints imposed by any deleterious effect on cement quality, refractory life, gas and material flow or potential emissions to the atmosphere.

In most kiln systems the fuel ash is incorporated into the clinker thereby changing the compound composition of the product. The main constituents of fuel ash are silica and alumina compounds which combine with the raw materials to become part of the clinker. The composition of fuel ash tend to limit the level of replacement of more conventional fuels, for instance rice husks have been used to replace 5-7 percent of traditional fuels since the ash contains 78 – 90 percent silica. Fuel ash with high content silica can on the other hand provide a very satisfactory means of increasing the silica modulus of the clinker, thus making it possible to reduce the amount of ground sand incorporated into the feedstock (Hewlett, 2004).

Approximately 95 percent of clinker consists of oxides of CaO, SiO₂, Al₂O₃, and Fe₂O₃ and the remainder consists of the so-called minor constituents. In cement manufacturing care is taken to avoid constituents which, even when present in small amounts (< 1percent), may have adverse effect upon the performance of the product and/or the production process. The most important of these are probably the oxides of potassium and sodium (K₂O and Na₂O) commonly known as alkalis. High levels of alkalis in cement, in the presence of moisture, give rise to reactions with

certain types of aggregates to produce a gel which expands and gives rise to cracking in concretes and mortars.

The alkali metals, Na_2O and K_2O have a very strong affinity for SO_3 and where there is sufficient sulphate present in the clinker, the alkalis are normally present as compounds of sulphates such as K_2SO_4 , Na_2SO_4 , aphthilalite $\text{Na}_2\text{SO}_4 \cdot \text{K}_2\text{SO}_4$ and langbeinite $2\text{CaSO}_4 \cdot \text{K}_2\text{SO}_4$ (Hewlett, 2004; Newman, et al., 2003). Higher levels of alkali sulphates in cements affect the reactivity of the cement, thus leading to possible setting problems (Hewlett, 2004). From kiln operational point of view, it is desirable that as much as possible the alkalis (and sulphates) get discharged from the system with the clinker. If this does not take place, the presence of these alkalis (and sulphates) can have an extremely disruptive effect upon production especially in kiln systems with high efficient heat exchangers such as the cyclones.

If chloride is introduced into the system either through the raw meal or the fuel, the melting point of the sulphates is reduced and sulphate–spurrite ($\text{C}_2\text{S} \cdot \text{CaSO}_4$), which is stable within the temperature range $900\text{--}1200^\circ\text{C}$ can also be formed. Sulphate–spurrite is considered to be associated with the formation of rings in cement kilns. It is recommended that chloride content must be kept low to avoid formation of kiln rings and preheater deposits (Taylor, 1990). Contents below 0.02 percent are preferred, though higher ones can be acceptable if a sufficient proportion of the kiln gases is bypassed or in less energy-efficient (e.g. wet process) plants. Ring formation is known to increase with an increase in the amount of excess sulfur over that which combines with alkalis (Hewlett, 2004).

Some of the waste materials used as alternative fuels in cement kiln systems such as polyvinylchloride (PVC), chlorinated hydrocarbons, sewage sludge, and meat and bone meal can increase the amount of chlorine (Cl) introduced into the system (Azad Rahman et al., 2013). Fuels containing high (> 0.7 percent Cl) can adversely affect the performance of some types of electrostatic precipitators on wet process kilns. It is also reported that in kilns with cyclone preheaters, only about 20 percent of the chlorine input is retained in the clinker, with the result that a recirculation chloride load of some 400 – 500 percent develops in the kiln/preheater system (Hewlett, 2004) . Clogging may occur in the cyclone pre-warmer if chlorine content of fuel is more than 0.2 – 0.5 percent. Chlorine content is also known to affect the quality of the product. High Cl content increases the corrosion of reinforcement in concrete. From quality point of view

most standards for Portland cements restrict the amount of chloride present to 0.10 percent of the raw meal feedstock. However, in preheater kiln systems operational problems normally manifest themselves long before this quality point is reached (Hewlett, 2004).

The effect of other trace elements such as fluorine, barium, chromium, lead, manganese, thallium, titanium, vanadium and zinc on quality of cement range from very small to negligible. However, it is important to note the exceptions of fluorine and zinc from this list. There are indications that the use of fluorine as a mineralizer may give rise to the build-up of excessive coating in the kiln and that this may be due to the formation of additional spurrite. CaF_2 acts both as a mineraliser and as a flux in promoting the formation of alite (Taylor et al., 2006; Newman et al., 2003). Small amounts of zinc (0.01 – 0.2 percent) have been reported to increase the reactivity of C3A6 and in consequence lead to possible setting time problems. However, the presence of up to 0.5 percent of ZnO does not appear to have a profound effect upon other hydraulic properties (Hewlett, 2004). The zinc content in tyres is, from cement quality point of view, the main constraint in the use of scrap tyre as a fuel. Type ash contains about 20 percent Zn (Saint-Jean et al., 2005).

2.4.Uses of biomass fuels in cement industry

Many different potential sources of biomass waste exist, such as sugarcane straw, coffee husks, and food oil waste. These and other by-products with recoverable calorific value can be used as fuels in a cement kiln, replacing a portion of conventional fossil fuels, like coal, if they meet strict specifications (Lechtenberg, 2008; CSI, 2002). Because biomass waste is made of 100 percent renewable organic matter, it has high potential for mitigating carbon dioxide emissions from the cement industry. However some challenges remain such as heterogeneity in terms of quality and quantity, they are also widely dispersed geographically, seasonality as most residue produced during harvesting season and existing competitive uses of the residue. Moreover, it is important to measure and quantify to what extent the quality, type and quantity of biomass fuel exert a profound effect on the quality of clinker produced (Azad Rahman et al., 2013). Consequently, selection of the proper type of fuel is vital for optimum efficiency. The calorific value, CO_2 emission and ash content as well as the moisture and volatile contents are the major limiting factors. Moreover, potentially high collection expenses because of scattered resources

and low biomass density of the alternative fuels remain also the main influencing factors for their choice and need to be studied (IFC, 2017).

2.5. Technological options for biomass burning in cement kilns

Biomass burning in cement kilns is a well-established technology, which can be purchased or custom-made in developing countries. Existing feeding systems of alternative fuels into kilns are robust and it is possible to feed in biomass ranging from small pellets to full-sized tyres. For ease of handling and achieving uniform calorific input into the kiln, it is important to reduce biomass materials to manageable sizes. For example, solid woody biomass needs to be chipped into small sizes, pre-dried, and unwanted materials such as stone and metal bits removed (Nicholls et al, 2008).

Biomass materials can be fed in two different ways: 1. it is possible to grind the pellet along with cement raw materials to feed as pulverized fuel. However, as a result of the low ignition temperature of biomass, fire may start during the milling process unless special precautions are put in place; and It may also affect the efficiency of the mill if the moisture content of the biomass is high (Mackes and Lightburn, 2003). 2. cement industry that use coal as a main source of energy can blend biomass or with coal to feed it into the kiln using a coal-feeding system or feeding through specially-made gates at the pre-calcination region is the safest choice.

2.6. Upgrading and characterization of biomass fuel

Biomass is the third largest natural source of energy in the world. It is among the renewable energies that are available for the achievement of the targets of reducing CO₂ emissions; reduce dependency on imported fossil fuel energy, and its energy utilization also emits less environmental pollution such as SO₂, NO_x and CO than fossil fuel. It is defined as the biodegradable fraction of the products and wastes of biological origin that come from agricultural activity, forestry and related industries. Its use as an energy source provides substantial socio-economic and environmental benefits, compensating its localized nature for its high availability. Moreover, biomass and biomass residues, if sourced in an environmentally and socially sustainable fashion, represent a vast – and largely untapped – renewable energy source for the countries of sub-Saharan Africa. For instance, Biomass can substitute for approximately 20% of process heat requirements of cement industry in Ethiopia without the need for major

capital investment (Yisehak Seboka, 2009). However, these large proportions of biomass or residues from commercial farms and from agro-industries cannot be used on-site due to limited demand in the immediate vicinity; as a consequence, residue tends to be disposed of wastefully. Moreover, its utilization as a solid fuel still has many drawbacks from its undesirable properties.

A disadvantage of biomass as compared to fossil fuel is its high and variable moisture content, low energy density per unit volume resulting in difficulties in its storage, distribution/transportation and suppresses its energy density (Arranz, 2012; Miranda, et. al., 2015). Moreover, the composition, moisture content, ash content and size of biomass is diversified depending on harvest dates and methods, weather conditions, and plant genetics, which limit their use as it is appeared and exhibit different behaviors in thermal processes and needs upgrading to meet the required quality (Lewandowski & Kicherer, 1997; Fagan et. al., 2012; Everard et. al., 2012) . Biomass is difficult for size reduction to reduce into small and homogeneous particles due to its high fibrous composition. In chemical properties, biomass has significant lower carbon content compared to fossil fuel and some types also have high ash content which is non-combustible and causes some problem for combustion process. Therefore an important step in the processing of biomass for energy purpose is reducing the moisture content, size of the biomass and densification (a process that compress raw materials) in order to obtain denser fuels, with homogeneous properties and size so that to ensure the required quality of product is received (Poddar et al., 2014).

The upgrading techniques of biomass have been widely studied to improve its undesirable properties. The torrefaction of raw biomass is an attractive upgrading technique that is a thermochemical treatment with operating temperature within the range of 200 to 300 °C. It is carried out under atmospheric condition and in the absence of oxygen. This process can remove moisture and low weight organic volatile components, depolymerise of cellulose lead to reducing fibrous structure, produce a dry, more hydrophobic solid product with increased in the energy density and greatly increase grindability (Bergman, et. al., 2005) . Densification is also another pre-treatment technique aimed to increase the density of biomass with a homogeneous properties and size (Poddar, 2014).

Pelletizing is currently the most extended one and the final product; pellet (the solid fuel from biomass) is convenient for use in the households, industry and district heating plants (Duca et al.,

2014). It has a diameter vary between 3 and 25 mm and the length generally varies between 5 and 40 mm (Morten et al., 2009). It occupies 10-30 times less space than fresh material so that its use decrease transport and storage cost. Global pellet production has considerably increased for the past years and between 2006 and 2012, pellet production worldwide grew from 7 to 19 million tons, with Europe and North America take the lion share, in the production and consumption of these densified products (Duca et. al., 2014; Miranda, et. al., 2015).

The main purpose of pelletizing a raw material is to reduce the volume and thereby increase the energy density. A typical biomass pelletizing operations consisting of three major unit operations-drying to about 10% (dw), size reduction (grinding) until it is suitable for pelletizing, and densification (pelletizing) to bulk density of pellets greater than 600 kg/m³ as shown in figure 1.

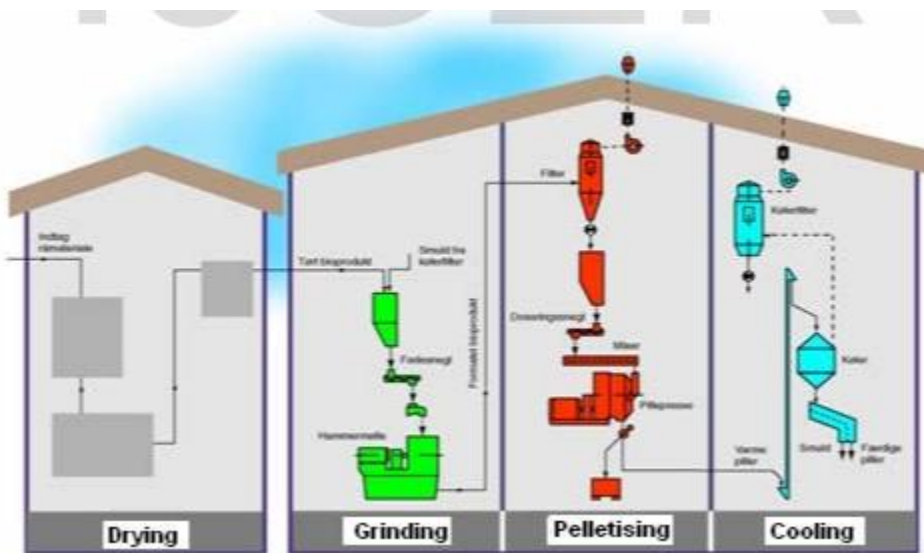


Figure 1 Flow diagram of the pelletizing process (Morten et al, 2009).

Pellet quality depends both on physical, chemical and mechanical properties of biomass (as a raw material) and pelletizing variables (such as pressure, temperature, etc.). The most important characteristics that needs to be analyzed for the evaluation of final product from different sources and became optimized to meet the standards sated includes: calorific value, moisture content, ash and sulfur content, bulk density, specific melting temperature of ash, volatile matter content,

alkali metal content and grain size (Oberberger, et.al., 2004; Gillespie et al., 2013; Biswas, et al., 2014; Japhet et al., 2015).

There were a lot of biomass residue proposed for production of pellet (briquette) in developing countries such as bean pod, cereal husk, cotton waste, wheat straw, paper waste, sawdust, wood chips, palm fiber, Coffee husk, groundnut shells, Rice husk, maize residue and other agricultural residues by finding suitable ratio of raw material, adhesive, and water for meeting highest heating value of such fuel pellet (IFC, 2017). In general, these are characteristics of the ideal energy biomass as they are produced in large quantity, low energy input to produce, low cost, composition with the least contaminants



Figure 2 biomass sources for pelletizing (adopted from Kiss and Alexa)

The energy content of raw fuel reported were summarized in the table 1 below which is in the range of 16.9-17.1 MJ/kg. However, it is difficult to find information about the levels of pellet production and application in the developing countries. Whereas, there is some global information on densified biomass fuels (DBFs) available in the form of pellet and briquettes from wood and agricultural residues.

Table 1 calorific value and proximate properties of different biomass residues/solid fuels

Solid fuels	HHV (MJ/Kg)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)	Moisture content (%)	Author
Coffee husk	16.8-18.8	2.5- 7.2	76.3-83.20	14.0-16.5	6.7-10.0	Bilhat Chala et al. (2015); Mhilu (2014)
Coffee parchment	18.5	0.5-1.5	79.14-85.8	13.7- 19.9	N.A	Chala et al. (2015); Paula et al., (2011)
Saw Dust pellet	19.8	1.3	83.4	15.3	N.A	Sánchez et al. (2014)
Cotton stalk	17.4	3.3-4.0	72.0-75.8	24.0	12.0	Henrich et al. (2014)
Rice husk	13.24-15.7	9.3-26.0	59.0- 69.0	14.3-19.0	8.8	Singh et al.(2013); Mhilu (2014)
Rice husk pellet/briquettes	15.2-17.6	16.1	68.2	15.7	12.7	Tokan et al.(2016); Efomah & Gbabo (2015)
Wheat straw	17.3	4.0-8.0	59-70	20-23	16.0	Henrich et al.(2014); Domalski et al. (1987)
Corn cob pellet	13.8	N.a	N.a	N.a	N.a	Kyauta et al (2015)
Ground nutshell pellet	13.9	N.a	N.a	N.a	N.a	Kyauta et al (2015)
Sugar can bagasse pellet	17.9-18.4	8.70	77.27-82.3	14.0-17.2	5.5	de Almeida et al, (2017); Paula et al., (2011)

N.a refers to not available

2.7.Coffee residue as alternative biomass fuel

Coffee is second most traded legal commodity next to petroleum. Millions of people from developing countries rely their livelihood on coffee production (Bilhat Chala et al., 2015). Ethiopia is the fifth largest coffee producing country and estimated total area covered by coffee is approximately 400,000 hectares, with a total production of about 200,000 tonnes of clean coffee per year (Gemechu, 2009; ICO, 2017). Coffee processing -removing outer layers of the freshly picked red cherries of the coffee plant which is comprised of about 68 percent pulp, 6-10 percent parchment, and 26 percent clean coffee beans, takes two different forms in Ethiopia as indicated in the figure 3 below: wet and dry processing. Each process produces a different quality of “green coffee” and residues with very different characteristics. In general, primary coffee processing, either in wet or dry method, generate huge amount of by-products used inefficiently, mostly seen as waste and dumped else were, which causes environmental problems/pollution.

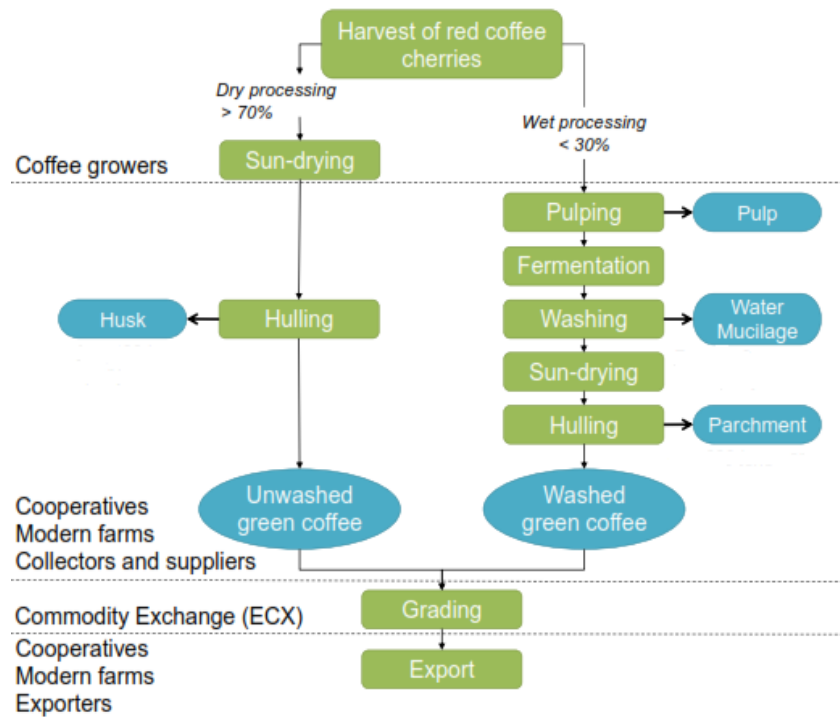


Figure 3 Coffee production chain in Ethiopia

In the dry process, the red cherries, which initially contain approximately 65% moisture content, are sun-dried until they reach approximately 10-12% moisture content. After the cherries are dry, they are put through a dry mechanical pulping (or decortivating) process in which the green coffee bean is separated from the outer residue material (skin and husk) of the cherry. The dry process removes the upper hard cover (the husk) and the inner skin (parchment) in the milling process. This residue material is generally blown out of the rear of the processing plant, where it accumulates during the processing season and eventually composts due to ingress of moisture. Heat generated during the composting of this waste occasionally spontaneously ignites the dry layers of recently added materials, commonly resulting in slowly smouldering heaps next to the processing plants.

In the wet process (washed coffee processing) the fresh cherries are milled using wet pulping machines to remove the outer skin and some of the mucilage. The processed cherry is then left to ferment in tanks for a specified period of time and the removal of the remaining mucilage is effected while the parchment is left intact. This is then shipped to the washed coffee processing facility in Addis Ababa where the parchment is removed. In general the mass balance during wet

coffee processing was based on the fact that for 100 kg of ripe cherries delivered to a washing station, 60% by weight end up as washed coffee pulp with the remaining 40% consisting of the green bean and endocarp or parchment. Of this, only 20 kg remain after sun-drying, which was processed to produce 16 kg of washed coffee beans ready for export and 4 kg of parchment as residue.

The average residue production per tonne of wet red cherry is about 600 kg or, based on green coffee bean production, the residue potential would be 1.4 times the mass of green beans produced (ESMAP, 1986). Indicated, the processes lead to the generation of large amounts of residues on the processing sites, which causes economic, social and environmental burden. On the other hand, the most pervasive problem faced by Ethiopian households and industries in the energy sector is the increasing scarcity and cost of fuels. However, a long-term solution for this problem might be the development and utilization of indigenous fuel substitutes such as biomass based fuels. Specifically percent of cultivated land occupied for large scale commercial farming and processing facilities where surplus coffee residues are available in large, economically accessible quantities, and form a potential fuel source. Coffee residue has an estimated potential of more than 280,000 tonnes produced annually in Ethiopia equivalent to 360,218 tonnes fuel wood (Bilhat Chala et al., 2015; ESMAP, 1986). From this total coffee residue coffee parchment (which is composed of 54% cellulose, 27% pentosans and 19% lignin) constitutes about 16,800 tonnes per year which is available elsewhere near the washed coffee processing plant (where the endocarp is removed prior to export) located in Addis Ababa. Moreover, increasing emphasis on the production of washed coffee in Ethiopia due to its attractive premium might lead to increase amount of coffee parchment in the next 5 years. Presently, most of the parchment is sold for 25 Birr per 40 kg sack to the local population who utilize the loose parchment as a cooking fuel. However, demand is irregular and storage of this bulky material is a problem. Residues, however, could be effectively used for the production of pelletized fuel as substitutes to fuelwoods, coal and fuel oil in cement factories and even households.

2.8. Specification of alternative fuel pellets

Quality standards are fundamental in order to meet the following requirements: guarantee a common national or international quality of fuel pellets; ensure legal compliance and security among the actors by defining responsibilities and duties; establish limit values and quality

indicators, for use, transport and storage; define technical characteristics for heating equipment; inform the final consumers about quality characteristics; ensure customer satisfaction and disseminate biomass fuel, be environmentally friendly.

The current state of the art in wood pellet market is focused on certification system, including requirements for pellet production and quality assurance, labeling, logistics and intermediate storage as well as delivery to costumers (ENplus, 2013). Pellets properties from international standards are presented in Table 2 below. ISO 17225-2 is a standard for wood pellets (International Organization for Standardization (ISO, 2014a), while ISO 17225-6 is a standard for non-wood pellets (International Organization for Standardization (ISO, 2014b), The European Pellets Standard EN 14961-1 is a general requirement for solid biofuels (European Committee for Standardization, CEN, 2010). The North American PFI Standard establishes requirements for wood pellets (PFI, 2011).

Table 2 Pellet specifications from international standards

Specification	ISO 17225-2	ISO 17225-6	EN 14961-1	USA PFI Standard
Diameter (mm)	6,8,12 ± 1	6- 10	6,8,10 ± 1	5.84-7.25
Length (mm).	3.15-40	3.15-40 3	15-40	≤ 42
Bulk density (kg m⁻³)	≥ 600	≥ 600	≥ 600	608.7-746.9
Moisture (%)	≤ 10	≤ 12	≤ 10	≤ 10
Heating value (MJ kg⁻¹)	≥ 16.5	≥ 14.5	≥ 16.5	-
Ash content (%)	≤ 0.7	≤ 6	≤ 1.0	≤ 2.0
Nitrogen, N (%)	≤ 0.3	≤ 1.5	≤ 0.5%	-
Sulphur, S (%)	≤ 0.04	≤ 0.2	≤ 0.05%	-
Chlorine, Cl (%)	≤ 0.02	≤ 0.1	≤ 0.3	< 300ppm

Basically there are parameters considered in the selection of fuels to use for cement industry and these are mostly linked to its effect on Kiln operation: Chlorine, sulfur, and alkali content which may build up in the kiln system, leading to accumulation, clogging, and unstable operation; excess in chlorine or alkali may produce cement kiln dust or bypass dust; high Water content may reduce the productivity and efficiency of the kiln system; the heating value is the key

parameter for the energy provided to the process; the ash content affects the chemical composition of the cement and may require an adjustment of the composition of the raw materials mix. And Clinker and cement quality: Phosphate content as it influences setting time, Chlorine, sulfur, and alkali content as they affect overall product quality; heavy metals such as Chromium which may cause allergic reactions in sensitive users (CSI, 2005).

Though there are no clear specifications for determining what would be a good biomass fuel for cement industry, Lafarge Cement in France, Italy and Sweden for example, has developed the following specifications to protect the environment and conserve the efficiency of their cement kilns (Mokrzycki et al, 2003; EC, 2003):

Table 3 Specification for RDF used in cement plants in France, Italy and Sweden

Parameters	Unit	Specifications		
		Lafarge (France)	Italy	Sweden
Calorific value	MJ/kg	>17	> 15	> 21
Moisture	(%)	< 10	< 25	10-30
Ash	(%)	< 0.5	< 20	0.6- 10
Chlorine content	(%)	< 0.2	< 0.9	< 1.0
Sulfur content	(%)	< 2.5	< 0.6	< 0.5
Heavy-metal contents	ppm	< 2500	< 500	< 2000

3. Materials and methods

3.1. Estimation of solid waste quantity by weight

The materials used to estimate quantities of coffee parchment generated at source includes: hand protective plastic gloves, plastic buckets for volume measurement, balance scale, plastic sheet, and plastic bags.

The actual quantity of coffee parchment generated were calculated after determining the amount of coffee parchment disposed per kilogram of wet coffee processing delivered to the facility, and by considering the amount lost and diverted for different reasons by the sector that produces the waste. The data collection were conducted in a daily bases and extended for over one month. Moreover, secondary sources such as previous recordings found in the processing industry and respective government organizations were also used to estimate waste generation per annum. Data on its seasonal variability was also collected as it is one of the major factors in the amount of waste generated in biomass production. This was done by making interview with the respective personnel.

3.2. Establishing an effective collection routes

One of the challenges in integrated waste management systems has been the high collection and transportation cost and its associated GHG's emission as the waste sources are scattered here and there and the vehicle cover long distance, faces high traffic jam while collecting and transferring the waste and etc. Therefore, a shortest waste collection route was investigated and proposed for the collection of coffee parchment from various coffee processing plants in Addis Ababa and conveyed these waste to the nearest transfer station so that to minimize the total cost of production of alternative fuel. The collection routes were identified based on the information obtained on the existing sources of the waste, collection and transfer center, the possible route between the source and to the transfer station and having taken in to account the restrictions to the road conditions and topography. About 37 source points available within Addis Ababa were identified for the network analysis study. Distance between these sources were identified according to their position located using GPS. Finally with the help of the Arc-GIS, the routes were chosen in a way that the resources used for collection, the length of route and time taken to

complete the collection is minimized. The route optimization process is described in figure 4 below.

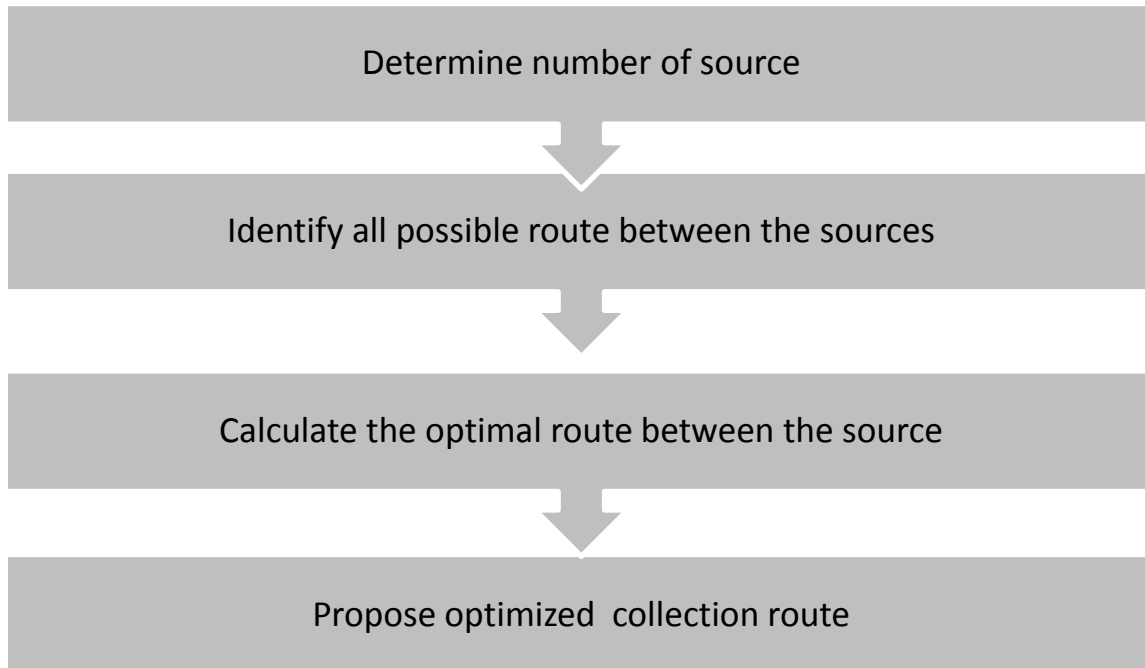


Figure 4 schematic representation of the phases of the methodology followed

3.3. Pelletizing coffee parchment

In this study coffee parchment was pelletized to enhance bulk density, to get proper aggregate stability and more homogenous biomass fuel after drying in an oven for one hour and grinded to pass a mesh screen size of 1.46 mm and using the optimum additive (molasses) to water ratio of 2:1. If it is above this ratio it becomes more viscous and difficult to spray, control the flow and may be not cost effective and the particles may not bind with the required density (low bulk density) below this ratio, as a result it can be easily break with limited force applied and get lost. So to get proper bulk density and enhance pellets aggregate stability the particle size we used and the ratio of the binding agent is optimum that led to relatively the highest heating value as compared to other trials made. Whereas making a pellet from the raw materials with its original size were not possible. The quantity of additives used to bind the dried coffee parchment were in accordance with the EU standards, which states additives that improve fuel quality, decrease emissions, or boost burning efficiency can make up to a maximum of 2% of the total mass of the

pellets (EPC, 2011). Pellet formation phases and pelletizing machine used in this study are indicated in figure 5



Figure 5 pellet formation phases from coffee parchment and pelletizing machine used

3.4.Characterization of coffee parchment

The equipment used during characterization of raw coffee parchment and its pellet were grinder, sieves, flask, funnel, porcelain dish, pipette, hot plate, electronic balance, ceramic and metallic crucibles, drying oven, muffle furnace (0-1200 °C), desiccators, elemental analyzer (EA 1112 Flash CHNS- analyzer), ICP-OES and oxygen bomb calorimeter.

3.4.1. Proximate analysis

Ash, volatile matter, fixed carbon and moisture content of the biomass are key parameters determined for estimating the quality/energy value of coffee parchment. They were determined in ASTU chemistry laboratory following ASTM standard procedure: Moisture content ASTM (D3173), ash content ASTM (D3174), volatile matter content ASTM (D3175), fixed carbon content ASTM (D3172) (Akowuah, 2012). Each parameter was determined in triplicates.

Percentage moisture content

The percentage moisture content (MC %) was found by weighing 2g of the sample (I) and oven drying it at 105°C until the mass of the sample was constant (A). The change in weight (I-A) was then used to determine the sample's percentage moisture content using the Equation below:

$$MC (\%) = \frac{[Initial\ Mass - Moisture\ Mass]}{[Initial\ Mass]} \times 100 \text{-----}1$$

Percentage volatile matter (VM %)

The percentage of volatile matter was determined by heating 2g of the samples in a crucible and placing it in a furnace to 925 °C for seven minutes in the absence of air and weighed after cooling in a desiccator. The percentage of volatile matter was calculated from the loss in mass of the sample after reducing the loss in mass due to moisture using the equation below:

$$VM (\%) = \frac{[A - B]}{A} \times 100 \text{-----}2$$

Where A is the weight of the oven dried sample and B is the weight of the sample after 7min in the furnace at 925°C.

Percentage ash content

The percentage ash content (AC %) was also determined by heating 2g of the sample in the furnace at a temperature of 550°C for 4h and weighed after cooling in a desiccator. to obtain the weight of ash (C). The percentage of ash content was then calculated using the Equation below:

$$AC (\%) = [C/A] \times 100 \text{-----}3$$

Percentage fixed carbon

The percentage of sample mass that remained after removal of volatile matter and ash content was used to determine the fixed carbon content and the percentage fixed carbon (FC %) was computed by subtracting the sum of VM (%) and AC(%) from 100 as shown in the Equation below:

$$FC (\%) = 100 - [A(\%) + VM(\%)] \text{-----}4$$

3.4.2. Heating or calorific values

Heating value which is the amount of fuel energy that can be released per unit mass or volume when the fuel is completely burned (in units of MJ/kg), of both the raw coffee parchment and pellet produced was examined at Addis Ababa, ministry of water, irrigation and energy laboratory in accordance with the ASTM procedure. The apparatus used was oxygen bomb calorimeter model: CAB001.AB1.C. For this analysis loading of biomass samples of about 1 g in to the bomb calorimeter was made and allowed to burn in the presence of oxygen pressurized to 30 bar inside a sealed container (bomb). The heat released from combustion was transferred to a mass of working fluid (water) that surrounds the container, allowing the heating values to be calculated, as the product of the mass and specific heat of the fluid and the measured temperature rise.

3.4.3. Ultimate and Chemical analysis

The raw coffee parchment and pelletized coffee parchment were analyzed in duplicate for the oxide contents according to specification of ASTM C 114/00 using XRF at Mugger cement industry, heavy metal analysis using ICP-OES after the sample were air dried and digested with HNO₃-HCl (aqua regia). And important chemical elements that makes up biomass, namely percentage Carbon, Hydrogen, Nitrogen and Sulfur, were determined using elemental analyzer (EA 1112 Flash CHNS- analyzer) available at Addis Ababa University. The oxygen content was determined by difference according to the formula below:

$$\text{Oxygen (\%)} = 100 - [\text{Carbon(\% Dry Basis)} + \text{Hydrogen(\% Dry Basis)} + \text{Nitrogen(\% Dry Basis)} + \text{Sulphur(\% Dry Basis)} + \text{Ash(\% Dry Basis)}] \text{---5}$$

4. Result and discussion

4.1. Biomass (coffee parchment) Generation and Management practice

As shown in Figure 6, the total biomass (coffee parchment) amounts generated in three consecutive years 2014, 2015, and 2016 were about 11,488 tonnes, 12,461 tonnes, and 10,584 tonnes, respectively. This is found to be 20% of the processed coffee cherry transported to wet coffee processing facility in Addis Ababa. And its generation reaches peak during the months of February to July.

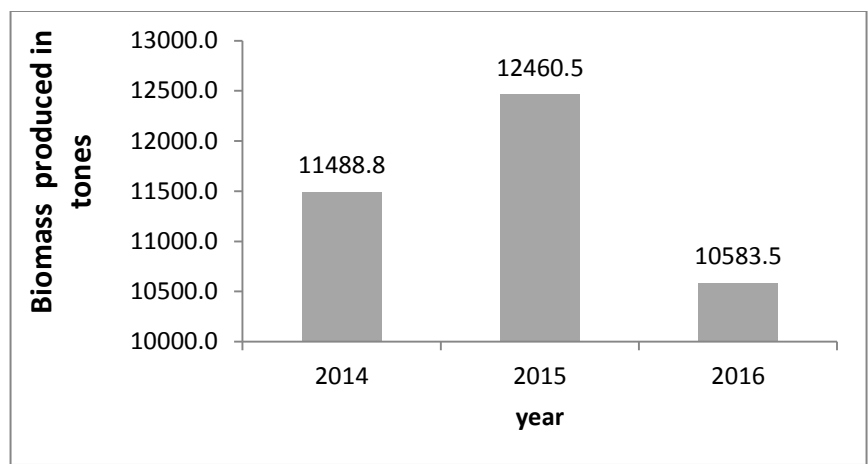


Figure 6 Estimated amount of biomass generated in Addis Ababa wet coffee processing facility in three consecutive years

The result clearly showed the amount generated per year is huge and if it is not properly managed or used inefficiently, it has potentially causes environmental burden /pollution. The estimated amount of coffee parchment found in this study were supported by recently reported data According to Bilhat Chala et al (2015) and ICO (2017) coffee residue has an estimated potential of more than 280,000 tonnes produced annually in Ethiopia. From this amount, coffee parchment constitutes about 16,800 tonnes per year which is available elsewhere near the washed coffee processing plant located in Addis Ababa. Moreover, increasing emphasis on the production of washed coffee in Ethiopia due to its attractive premium might lead to increase amount of coffee parchment in the next 5 years.

However, this huge amount of by-products has been used inefficiently, mostly seen as waste and dumped else were near the washed coffee processing plant. This huge amounts of waste generated mostly managed inefficiently and accumulated at source or at collection site/ transfer station. Very recently individuals started sale the parchment for 25 Birr per 50 kg sack to the local population who utilize the loose parchment as a cooking fuel. However, demand by the local population is irregular and storage of this bulky material at the existing site might have social, economic and environmental implications as the site would not meet technical requirements.

4.2.Establishment of effective waste collection route

Biomass collection and transfer is a very important function and is an important step in any wasted resource management programs as one of the challenges in recycling systems has been the high collection and transportation cost (represents 80–90% of solid waste management budget in low income countries, and its associated GHG's emission (Nuortio et al., 2006; Aremu, 2013). This is mainly because of the biomass sources are scattered here and there and low bulk density so that vehicles cover long distance, suffer from high traffic jam while collecting the biomass and etc. Therefore in this study collection route that minimize the length of each waste collection were proposed based on distance, topography, condition of the roads as shown in figure 7

All possible routes between biomass source (considering 37 wet coffee processing facilities) and the existing transfer station were marked with black and the shortest route between the source and transfer station was marked by red (Figure 7). Existing biomass collection and transportation route were not well known and difficult to gather the information as different groups were involved in the collection of the biomass from the source. Considering that all start the journey from a source and visit the various sources located at different sites transportation of the biomass covers a total distance of 117.6 km (Figure 7).

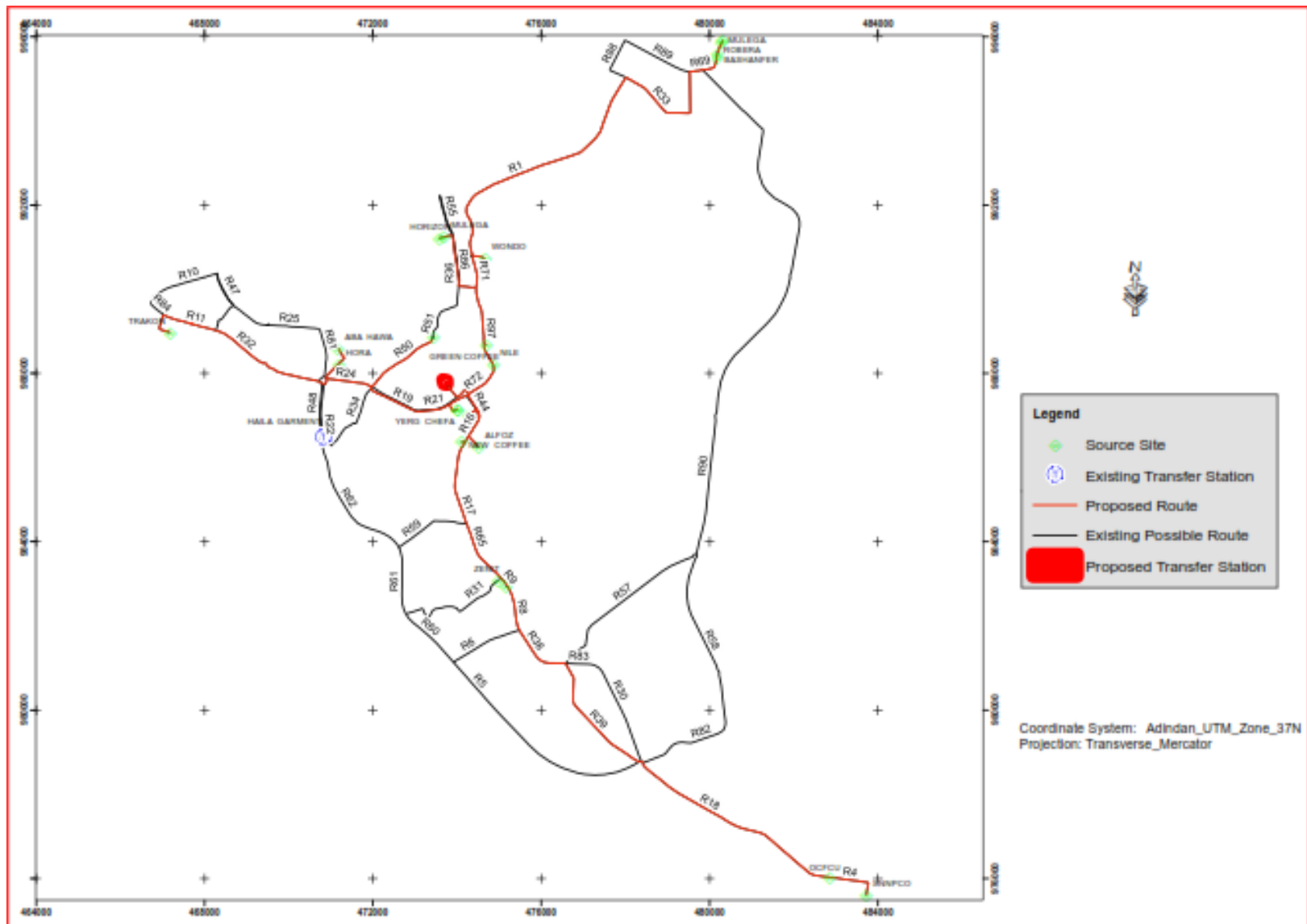


Figure 7 existing roads and proposed route between biomass sources and with transfer station

Moreover, during the site visit we observed at the collection station located at Haile Garment, the biomass was prepared for different users using a 50 kg sacks and the end user again transport the material using different vehicles and animal transportation and ends to individual household in the nearby. Remaining biomass (approximately > 50%) is accumulated and become mountain of waste at the transfer station. Means that it require a solution that improves the vehicle routing, demand irregularity, and locating proper collection site for upgrading the quality of biomass fuel to make use of the social, economic and environmental value of the by-product.

Considering the existing transfer station located at Haile Garment (Figure 7) the proposed collection route (marked by red) covers a total distance of 53.6 km. Whereas the optimized route calculated after identified the position of the transfer station using Arc-GIS software were shown in figure 8 and covers a total distance of 41.6 km from the biomass source to the processing plant/transfer station located around Kaliti, Addis Ababa. In this site the pellet might be produced from gathered coffee parchment and transferred the produced pellet to the cement industry. This optimization considered the quantity of biomass generated, number of wet coffee processing facility, and their arrangement and between distances to cover the whole processing facility to locate a new transfer stations.

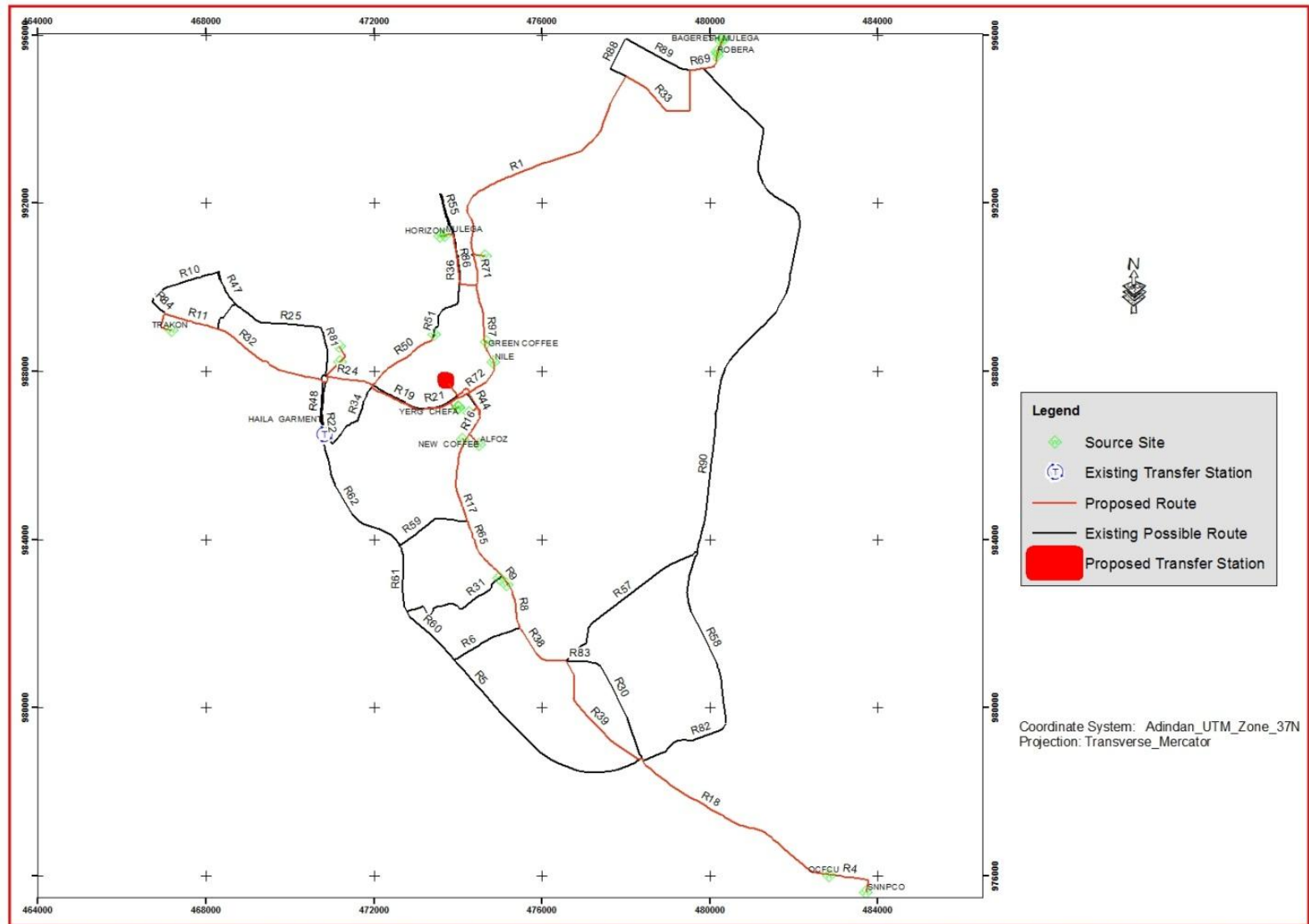


Figure 8 existing roads and proposed route between biomass sources with a newly identified transfer station

Total distance were originally calculated from each road length that has been present between the sources and then to the transfer station (Table 4)

Table 4 Road distance of each path between the sources and proposed transfer station

path	Distance (m)	path	distance	path	distance □
R8	1099.58	R21	2021.36	R71	741.96
R17	2010.40	R18	5306.01	R72	1027.81
R38	1498.19	R9	229.37	R86	1222.48
R39	3135.87	R65	1581.49		
R69	861.46	R24	1110.15		
R97	1359.46	R32	2868.57		
R1	6401.86	R33	1853.91		
R11	1338.99	R36	688.74		
R16	519.35	R44	599.81		
R19	2254.86	R50	1853.53		

4.3.Characterization of coffee parchment, and its pellet.

Analysis of coffee parchment and the pellet Properties was conducted to determine the amount of fuel energy that can be released per unit mass or volume when the fuel is completely burned (heating or calorific values, in MJ/kg), the analysis result also indicates the most likely energy conversion process and to what extent the quality of the materials meet the specification set for different uses specifically their suitability as a feedstock to the cement industry.

4.3.1. Proximate analysis

The proximate analysis classifies the fuel in terms of its moisture, volatile matter, fixed carbon, and Ash. The result of proximate analysis of the raw and pelletized coffee parchment calculated on a dry weight basis was presented in table 5.

Table 5 Proximate Analysis and heating value of coffee parchment pellet and raw coffee parchment measured in dry weight basis

Sample code	Moisture content	Volatile content	Fixed		HHV
			Ash	carbon	
					(cal/g)
CP-Pellet	11.2 ± 0.1	86.1 ± 2.4	5.97 ± 0.7	7.97 ± 2.0	6676.4 ± 60.7
CP-Raw	11.5 ± 0.1	93.3 ± 0.9	0.38 ± 0.04	6.29 ± 0.9	4433 ± 8.7

Moisture Content

Table 5 shows, the moisture content of coffee parchment and its pellet were 11.5% and 11.2 %, respectively. These results obtained for both materials were in accordance with ISO 17225-6 standard for non-wood pellets sated to use as alternative fuel (< 12%) (ISO, 2014b) and meets requirements of cement industry (<30%) specified by different countries (Mokrzycki et al., 2003, Uliasz-Bochenczyk, 2003; EC, 2003), but slightly higher than specifications described by Lafarge cement industry, France (Mokrzycki et al, 2003). Moreover, the moisture content of the studied samples were lower as compared to other biomass reported by Tokan et al.(2016); McKendry (2002); Efomah & Gbabo (2015); Henrich et al.(2002) & (2004), such as the moisture content in cotton stalk (12.0%), rice husk pellet (12.7%), barley straw (30%), wheat straw (16.0), and wood (20%). Thermal conversion usually requires low moisture content feedstock typically (< 50%) thus this result indicated that the moisture contained in the studied materials were not hinder ignition, adversely impact the overall energy balance for the conversion process and slow the rate of combustion to a large extent since there was no excessive moisture in the material (McKendry, 2002). Moreover, as the moisture content can change during handling, transportation and storage by uptake or release of moisture from or to the surrounding management during handling may affect the moisture content of the material which subsequently affects the analytical result. The higher moisture content in the coffee parchment as compared to other biomass materials (**refer table 1**) indicated coffee parchment has more void spaces within the dead cells and within the cell walls responsible to store moisture in spaces (Demirbas, A. 2004)

Ash Content

Ash which is the inorganic matter left out after complete combustion of the biomass is an important property to be measured for solid and liquid fuels since it influences both the handling and processing cost of overall biomass energy conversion (McKendry, 2002). As shown in table 5, the ash content of the studied materials was found to be 5.97% in the pellet formed and 0.38% in the raw coffee parchment. Significantly higher ash content in the pelletized coffee parchment is due to increased elemental composition of the pellet as a result of the binding agent used (molasses), thereby affecting ash content of the final product (Kuokkanen et al., 2011). However the ash contents of both materials is below ISO 17225-6 standard for non-wood pellets sated to use as alternative fuel (< 6%) (ISO,2014b). And meets requirements of cement industry (<20%) specified by different countries (Mokrzycki et al. 2003; Uliasz-Bochenczyk, 2003; EU Commission, 2003), indicated that both the coffee parchment and its pellet is suitable for thermal utilization. Moreover, ash content found in the coffee parchment was lower than reported amount in coal (> 8%) and other woody and non-woody biomass such as sugar cane bagasse (8.7%), wheat straw (4-8%), and Rice husk and its pellet (9.3-26%) (Tokan et al., 2016; Efomah & Gbabo, 2015; Henrich et al., 2002; McKendry, 2002). But the ash content found for the coffee parchment pellet in this study was higher than specifications described by Lafarge cement industry, France (Mokrzycki et al, 2003) and those found in other standards defined by ISO 17225-2 (≤ 0.7); the European Pellets Standard for solid biofuels EN 14961-1(≤ 1.0) (CEN, 2010). The existence of higher ash content in a fuel usually contribute negatively to its energy content and operational efficiency that leads to lower calorific value, the reactivity of the fuel and lowering the calorific value. Furthermore, the high ash content will lead to corrosion and fouling of combustion equipment so that regular cleaning of the bed or grate needs to be maintained (Efomah & Gbabo, 2015; McKendry, 2002).

Volatile Matter

The other useful parameter is a volatile matter which provides a rough indication of the reactivity or combustibility of the fuel. This property also helps us in the estimation of the length of a flame. For the biomass analyzed in this study a volatile content of coffee parchment and its pellet was recorded to be 93.3 %, and 86.1%, respectively (Table 5). This high volatile matter contents was in agreement with the justification that biomass typically has a high volatile matter content (> 80%) (Efomah and Gbabo, 2015) and the result reported by Montenegro Camacho et al.

(2016) for coffee pellets (86.1%). The higher volatiles in raw coffee parchment than its pellet may be because of chemical and physical transformation of volatile matters in to volatile gases and fixed carbon up on drying and pelletizing. The higher volatiles indicates that coffee parchment can easily ignites under low temperature and during combustion will volatilize and burn as a gas in combustion chambers. Comparison of volatile matters in the studied material and other solid fuels confirmed that higher volatile matters were recorded in the coffee parchment than many other woody and non-woody biomass such as saw dust, rice husk, cereal straw, sugarcane bagasse and cotton husk which is found to be in the range of 59 – 83.4% (Sánchez et al., 2014; Henrich et al., 2004; Singh et al., 2013; Mhilu, 2014, Tokan et al., 2016); Efomah & Gbabo, 2015; Henrich et al., 2002; Domalski et al., 1985). The high volatiles in the studied materials give a faster combustion rate while devolatilizing during pyrolysis. And this will make coffee parchment attractive for the combustion process (Xing Yang et al., 2017). This difference may be due to differences in the chemical composition of the used biomass as well as the operations condition such as fast pyrolysis at a temperature of 925 °C might be responsible for the observed more volatile matter in material used in this study. The volatiles might consists of permanent gases like CH₄, CO₂, CO, H₂ and lower molecular weight hydrocarbon vapors, which forms syn-gas or the bio-oil after condensation (Montenegro Camacho et al., 2016).

Fixed Carbon

The fixed carbon is the mass remaining after the releases of volatiles, excluding the ash and moisture contents. This fixed carbon of a fuel is the percentage of carbon available for char combustion during pyrolysis (McKendry, 2002; Mohan et al. 2006). Furthermore, the fixed carbon in a material gives a rough estimate of heating value.

As shown in table 5 fixed carbon content of the raw coffee parchment and its pellet is found to be 6.29 ± 0.9 and 7.97 ± 2.0 percent, respectively. The fixed carbon contents was higher than the result reported by Montenegro Camacho et al.(2016) for coffee pellets (5.2%) and lower than the result reported by Bilhat Chala et al. (2015) and Paula et al.(2011) for raw coffee parchment (13.73% and 19.90%, respectively). This might be due to change in composition or operational condition. The observed lower fixed carbon content in coffee parchment than its pellet in table 6 may be because of chemical and physical transformation of volatile matters in to

fixed carbon up on drying and pelletizing. Comparison of fixed carbon content in the studied material and other solid fuels confirmed that unlike the volatile matter contents lower fixed carbon contents were recorded in the coffee parchment than many other woody and non-woody biomass such as saw dust, rice husk, cereal straw, sugarcane bagasse and cotton husk which is found to be in the range of 14.0 – 24.0% (Sánchez et al., 2014; Henrich et al., 2004; Singh et al., 2013; Mhilu, 2014, Tokan et al., 2016); Efomah & Gbabo, 2015; Henrich et al., 2002; Domalski et al., 1985). This variation might be related to differences in the chemical composition of the used biomass as well as the operations conditions (Montenegro Camacho et al., 2016). And the result implied that lower percentage of carbon is available for char combustion during pyrolysis in the studied materials as compared to other biomass in the respective operation conditions such as temperature, heating rate, humidity and residence time.

4.3.2. Heating Value

It is a key parameter which defines the quality of alternative fuel and It makes the principal parameter which is decisive for the share of the conventional fuel which may be substituted in the clinker manufacturing process. The heating value may be reported on two bases. The higher heating value (HHV) represents the heat value released when the fuel is burnt in air, including the latent heat contained in water vapor. The lower heating value (LHV) is the net heat value available for subsequent use and it is based on gaseous water (McKendry, 2002). The difference between HHV and LHV is the latent heat of the product water.

The heating values of coffee parchment and its pellet indicated in table 5 are the gross heating value in dry basis and it was found to be 4433 ± 8.7 and 6676.4 ± 60.7 cal/g for the raw coffee parchment and its pelletized form, respectively. Their MJ kg⁻¹equivalent was 18.56 and 27.95, respectively. The heating value recorded makes coffee parchment to have comparable values to common fuel woods and indicated promising potential source for renewable energy production. Moreover, the highest heating value in pellets from coffee parchment mainly attributed to complete combustion of denser materials and more uniform properties of the pellet than the raw biomass as well as high energy value additives (molasses) to facilitate binding increased the heating value of pelletized coffee parchment when compared to the raw coffee parchment and other woody and non-woody materials. As reported in different literatures different kinds of coal

have the gross heating value ranges from 20 to 30 MJ/kg; charcoal (29.6 MJ/kg); nearly all kinds of lignocellulotic biomass fall in the range of 15-19 MJ/kg and for most agricultural residues, the value fall in the ranges of 15-17 MJ/kg. for instance the heating vlaue found in the coffee parchent was higher than reported amount in woody and non-woody biomass such as sugar cane bagasse (17.9-18.4 MJ/kg), wheat straw (17.3 MJ/kg). Rice husk (15.2-17.6 MJ/kg), cotton stalk (17.4 MJ/kg) and saw dust pellet (19.8 MJ/kg) (Tokan et al., 2016; Efomah & Gbabo, 2015; Henrich et al., 2002; McKendry, 2002; Sánchez et al., 2014). Moreover, the heating vlaue of the pellet was higher than the result reported by Montenegro Camacho et al.(2016) for coffee pellets (18.4 MJ/kg) where as the observed HHV for raw materialwas lower than the result reported by Chala et al. (2015) (19.70 MJ/kg) and Paula et al.(2011) (4441.74 cal/g) for raw coffee parchent. The heating value of both materials is above all the ISO standards sated to use as alternative fuel (≥ 16.5 MJ/kg) (ISO, 2014). And meets minimum requirements of cement industry (>15 MJ/kg) specified by different countries (Mokrzycki et al., 2003; Uliasz-Bohenczyk, 2003; EC, 2003). This indicated that both the coffee parchent and its pellet is suitable to be used as alternative energy source and can be used in the clinker sintering zone for proper kiln operation and satisfactory quality of the clinker product (Duda., 2004).

4.3.3. Ultimate analysis

The ultimate analysis generally reports the elemental carbon (C), hydrogen (H), Oxygen (O), Nitrogen (N), and sulfur (S) composition in the solid fuel.

Table 6 Percent of organic matter (OM) and ultimate analysis of raw coffee parchent and its pellet form measured in dry weight basis.

Sample code	OM [%]	C [%]	H [%]	O[%]	N [%]	S [%]
CP-Pellet	91.7 ± 0.6	45.5 ± 0.5	6.5 ± 0.002	41.53	0.4 ± 0.04	0.1 ± 0.07
CP-Raw	N.D	43.5 ± 1.5	5.3 ± 0.6	50.12	0.5 ± 0.02	0.2 ± 0.03

N.D-not determined

Table 6 shows the elemental composition of the coffee parchent and its pellet. The high C (43.5% and 45.5%) and H (6.5% & 5.3%) content of both the raw coffee parchent and its pellet

respectively confirmed both materials have high energy content. The materials with a relatively higher C and H percentage have more energy density and higher HHV because of C-C bond release more chemical energy and during combustion hydrogen is converted to H₂O, which significantly contributing to the overall heating value. As compared to other biomass materials it has shown higher carbon percentage than the carbon content reported in rice husk (31.47-39.1%), peanut shell (41.5%), wheat straw (43.5%) and soybean pod (42.5%). However, it is lower than wood residue (48.6-51.6%) (Paula et al., 2011; Braz and Crnkovic, 2014). The result in table 6 also showed that the weight content of hydrogen was higher in the studied materials as compared to the H content in rice husk (5.3%), wheat straw (5.9% and saw dust (5.2%) as reported by Singh et al.(2013) and Demirbas (2004). The lower N and S content of the coffee parchment fuel (table 5) indicated there will be a minimal release of oxide of Sulfur and Nitrogen to the atmosphere up on combustion so that the burning of coffee parchment or its pellet will not cause environmental pollution. Overall, it was observed from the elemental analysis result in table 6 that the laboratory made pellet have relatively higher C, H percentage and lower N and S content as compared to other biomass materials that made of coffee parchment have a suitable property for its use as alternative fuel. Moreover, the percentage of carbon in the coffee parchment was originally comes from the atmospheric CO₂ which became part of the plant matter during photosynthesis.

During combustion of the coffee parchment, it is mainly transformed back into CO₂, which is again released to the atmosphere and taken out of the atmosphere by the species during the growth phase (Intergovernmental Panel on Climate Change, 2006). Therefore, its production and usage as fuel occurs on a very short time scale, the entire cycle is said to have zero net impact on atmospheric carbon emissions.

The relationship between measured parameters with HHV of the studied materials clearly showed carbon and hydrogen content and HHV was positively related. This is on account of the fact that C and H are responsible for the energy content in biofuels, due to exothermal reactions that take place with O₂ during combustion, generating CO₂ and H₂O, respectively. Even though lower fixed carbon content in the studied materials was observed as compared to other reported results of the same material by Paula et. al. (2011) and other materials (seen in table 1), this were

not accompanied by lower HHV as expected implies that it is rather the total carbon residue in the biomass affect the heating value of the materials and optimizing the operation conditions is mandatory to compare the HHV found in different materials. This justification is in line with the statement by Paula et al. (2011) that a high positive correlation was found between HHV with volatile matters, carbon and hydrogen contents.

4.3.4. Ash oxides contents

Most chemical elements from the fuel ash are incorporated into the cement clinker. Moreover the level of alkali metals is also important for any thermo-chemical conversion process (McKendry, 2002). Therefore in order to ensure the cement quality and process stability, it is necessary to control and know the levels and composition of all chemical inputs via the fuel. The results of the oxide analysis of ash of coffee parchment and its pellet were shown in table 7

Table 7 Oxide analysis of coffee parchment pellet and raw coffee parchment in comparison with reported value of wheat straw (Henrich et al., 2014); and Coal (Odunayo et al., 2016)

Sample code	CaO	MgO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O
	[%]						
CP-Pellet	29.91	5.95	8.76	1.09	1.06	0.36	0.01
CP-Raw	16.32	4.32	6.38	1.12	0.77	0.25	0.00
Wheat straw	0.3	0.1	3.6	-	0.1	2.2	-
Coal	0.18	0.12	16.9	11.4	0.37	0.62	0.14

As shown in table 7 the silica content of the coffee parchment and its pellet (6.38% and 8.76%, respectively) was much lower than coal. However, it has an implication that the fuel ash may supplement the silica required for clinker usually ranges from 19.7-23.0 % with proper formulation, which in turn can contribute in reducing the need of raw material and making the cement production more economical (Hewlett, 2004). The percentage of calcium oxide in the studied material ash (16.3 and 29.9%) was much higher than coal and wheat straw with the amount appreciated in the coffee parchment pellet (table 7). This might be due to the molasses added to facilitate binding of particles during pellet formation. The result confirmed that the fuel ash can also contribute to supplement the CaO required from limestone for clinker formation which constitutes about 63-67%. The analysis result with respect to magnesium oxide indicated coffee parchment pellet contained higher percentage as compared to coal (Table 7). This

confirmed that the studied material can also be a good source of MgO. However, careful design of the fuels and the raw materials is required to influence the final clinker composition. An excessive amount of magnesia (usually above 5 % as a whole), in the clinker can crystallize out from the flux as a periclase, in which its presence has been associated with long term unsoundness and causes delayed expansion (Hewlett, 2004). The analysis result in table 7 showed aluminum oxide percentage in the studied material was much lower than coal, but relative to the percentage required in clinker formation (3-7 %) the amount in coffee parchment (1.02%) would also significantly contribute to reduce the raw material demand in cement industry. The main function of iron oxide in the cement production is as a fluxing agent and clinker composition with respect to Fe_2O_3 is in the range of 1.5-4.5%, indicated the Fe_2O_3 content in the coffee parchment pellet (1.06%) as shown in table 7 can be a good source of iron oxide with proper formulation and its amount was slightly higher than the amount in coal. As shown in table 7 the content of minor oxides referred to as alkalis in cement (Na_2O and K_2O) are of particular interest and found to be 0.01% and 0.36%, respectively in coffee parchment pellet and lower than reported percentage in coal. These alkalis basically react with active silica in aggregate and produce what is called alkali-silica gel of unlimited swelling under favorable conditions of moisture and temperature which causes disruption and pattern cracking and blockages of air ways in the furnace (McKendry, 2002). However the content in the studied materials were less than the optimum limit indicated in the clinker composition which is about 0.5% with respect to K_2O and about 0.2 % with respect to Na_2O .

4.3.5. Heavy Metals contents

The presence of heavy metals in the cement processing will affect overall product quality as it become completely embedded in the clinker structure and depending on degree of volatility heavy metals such as chromium may also cause allergic reactions in sensitive users. The result of heavy metals found in the coffee parchment pellet is presented in table 8. The contents of heavy metals in coal as reported by Odunayo et al. (2016) were also included for comparative presentation.

Table 8 Heavy metal analysis result of coffee parchment pellet and in coal as reported by Odunayo et al. (2016)

Sample	Cr	Cu	Zn	Cd	Ni	Pb
			[mg/kg]			
Coffee parchment	3.8	4.0	10	< 0.05	1.5	0.3
Coal	N.a	32.8	38.6	N.a	20.6	7.02

N.a- not available

Table 8 shows that the levels of heavy metals found in coffee parchment pellet were lower than coal. Moreover the result confirmed coffee parchment pellet meets minimum requirements of cement industry (< 500) specified by different countries (Mokrzycki et al., 2003; Uliasz-Bohenczyk, 2003; EC, 2003).

5. Conclusions and recommendations

The viability and prospects of future existence of cement industry depend on the development or use of locally available alternative fuels such as wasted resources from different sectors/industry to partially substitute fossil fuels demand to heat its kilns. To this end applying the principles of industrial ecology has a number of benefits: above all contributes for considerable energy cost reduction, have significant ecological benefits of conserving non-renewable resources, reducing net CO₂ emissions per ton of cement, and it encourages the creation of new utilization networks by favoring the development of recycling. Therefore, in this study development of alternative fuels from agro-processing industry, specifically from wet coffee processing facility which is not well known in Ethiopia was investigated to be used in the cement industry.

It was investigated by: determining potential sources of coffee processing by-products (coffee parchment), establishing optimum route for collection, and estimating quantity of coffee parchment generated, characterizing the quality and type of raw biomass fuel and upgrading the fuel so as to enhance transportation, handling and utilization with optimum efficiency of kiln and without degrading the quality of clinker produced.

The different analysis result for the first time confirmed that:

The quantity of coffee parchment generated in Addis Ababa city within a radius of 41.6 Km were on average 11,511 tonnes per year, Moreover, increasing emphasis on the production of washed coffee in Ethiopia due to its attractive premium might lead to increase amount of coffee parchment in the next 5 years to about 16,800 tonnes per year which is dumped elsewhere near the washed coffee processing plant or has been used inefficiently and irregularly by the local population who utilize the loose parchment as a cooking fuel. However, this could be effectively used for the production of pelletized fuel as substitutes to coal and fuel oil in cement factories.

proposed route that minimize the length of each waste collection and transportation cost should consider the location of available wet coffee processing facility and potential transfer site in the nearby, distance, topography and condition of the roads. Consequently the optimized collection route may cover a total distance of 41.6 km.

the coffee parchment has relatively better fuel characteristics as compared to many biomass fuel such as rice husk, cereal straw, sugar cane bagasse and meet the required quality to be used as alternative solid fuel as most the proximate and elemental analysis result falls in the standards specified by different organization and countries with the exception of its low energy density per unit volume and size variability resulting in difficulties in its storage, transportation and, limit their use as it is appeared and exhibit different behaviors in thermal processes and needs upgrading to enhance the heating value and meet the required quality.

Upgrading of coffee parchment by pelletizing made the feedstock material more denser and have uniform size as result improved heating value (up to 28 MJ/Kg), fixed carbon content, Hydrogen, silica and other oxide contents were recorded

Ash oxides content particularly CaO, MgO, Fe₂O₃ were found relatively higher level in the studied material as compared to coal and even the silica and alumina content In the coffee parchment confirmed that the fuel ash may supplement sufficient silica and Al₂O₃ required for clinker formation up on careful design of the fuels and the raw materials required in the final clinker composition. Overall this may reduce the raw material demand in cement industry in addition to its contribution to supplement fuel demand which rely on imported coal.

Finally, even though the main parameters related to kiln operation and clinker quality were analyzed in order to evaluate the coffee parchment and its pellet quality, it would be necessary to investigate further the effect of additives specifically used to facilitate binding on the heating value and other properties as the observation in this study indicated the molasses added might contribute for the higher proportion of silica and higher heating value of the pellet; furthermore more refined investigation on relationship of different quality parameters with the heating value of the materials would be required as well as enhancing the fuel quality through chemical and thermal treatment of the feedstock materials in addition to pelletizing.

6. Reference

- Akowuah (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. *International Journal of Energy and Environmental Engineering*, 3-20.
- Aremu, A.S. (2013). In-town tour optimization of conventional mode for municipal solid waste collection. *Nigerian J. Technol.* 32 (3), 443–449
- Arranz, J. I. (2011): Analysis of Densified of the Combination from Different Biomass Waste. Doctoral Thesis, University of Extremadura, Badajoz, Spain.
- ASTM standard (2004), Standard test method for gross calorific value of refuse derived fuel by the bomb calorimeter. USA: ASTM International.
- Azad Rahman, Rasul M. G., Khan M. M. K., and Sharma S. (2013) Impact of Alternative Fuels on the Cement Manufacturing Plant Performance: An Overview,” *Procedia Engineering* 56 (2013): 393–400, doi:10.1016/j.proeng.2013.03.138.
- Battelle (2002). Toward a sustainable cement industry: climate change Sub study
- Bergman , P. (2005). Torrefaction for entrained-flow gasification of biomass.
- Bergstrom D., Israelsson S., Ohman M., Dahlqvist S. A., Gref R., Boman C., and Wasterlund I.(2008). Effect of raw material particle size distribution on the characteristics of Scots pine sawdust fuel pellet. *Fuel Processing Technology*, 89; 1324-1329.
- Bilhate Chala, Latif S, Muller J. (2015). Potential of By-Products from Primary Coffee Processing as Source of Biofuels
- Biswas, A.K.; Rudolfgsson, M.; Broström, M.; Umeki, K. (2014). Effect of pelletizing conditions on combustion behaviour of single wood pellet. *Appl. Energy*, 119, 79–84.

- CEMBUREAU. (1999). Environmental Benefits of Using Alternative Fuels in Cement Production. Brussels: The European Cement Association.
- CEMBUREAU. (1997). Best available techniques for the cement industry. Brussels: Cembureau
- CEMBUREAU. (2013). Raw material substitution. European Cement Association.
- Cement Sustainability Initiative (CSI, 2002). Our Agenda for Action. Published by the CSI and WBCSD. in available at www.wbcscement.org
- Cement Sustainability Initiative (CSI, 2005). Guidelines for the Selection and Use of Fuels and Raw Materials in the Cement Manufacturing Process. Published by the CSI and WBCSD. available at wbcscservers.org.
- de Almeida L.F.P., Sola A.V.H., Behainnet J.J.R. (2017). Sugarcane bagasse pellets: characterization and comparative analysis. *Acta Scientiarum*, 39 (4), p. 461-468.
- Demirbas, A. (2004). Combustion characteristic of different biomass fuels. *Progress in Energy and Combustion Science*.
- Domalski, E. S., Jobe, T. L., Jr & Milne, T. A. (1987). *Thermodynamic Data for Biomass Materials and Waste Components*. American Society of Mechanical Engineers, NY.
- Duca, D.; Riva, G.; Foppa Pedretti, E.; Toscano, G.(2014). Wood pellet quality with respect to EN 14961–2 standard and certifications. *Fuel*, 135, 9–14.
- Duda, J. (2004). Energy saving and pro-ecological techniques of clinker burning. Polish: Publishing House of Silesian Institute.
- Ebeling J.M. and Jenkins, B.M. (1983). Physical and chemical properties of biomass fuel”, American Society of Agricultural Engineers, Winter meeting December 13-16, Chicago, Illinois.
- Efomah A.N. and Gbabo A. (2005). The physical, proximate and ultimate analysis of rice husk briquettes. *International journal of innovative science, engineering and technology*, 2(5).
- ENplus. (2013). Handbook for the certification of wood pellets for heating purposes (version 2.0). Brussels, BE: European Pellet Council.
- ESMAP (1986). Agricultural residue briquetting pilot projects for substitute household and Industrial fuel. UNDP/World Bank Technical report
- European Comitee for Standardization. (CEN, 2010). EN 14961:2010 – Solid biofuels — Fuel specifications and classes, Part 1– General requiriments. CEN/TC 335. London, EN: CEN.

- European Commission (EC) (2001). Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries.
- European Commission directorate general environment (2003). Refuse derived fuel, current practice and perspectives (b4-3040/2000/306517/mar/e3) final report.
- European Pellet Council (2011). Handbook for the Certification of Wood Pellets for Heating Purposes, European Pellet Council, Brussels, Belgium,
- Everard C.D, Fagan C.C, McDonnell K. (2012). Visible-near infrared spectral sensing coupled with chemometric analysis as a method for on-line prediction of milled biomass composition pre-pelletising. *J Near Infrared Spectrosc*; 20:361–9.
- Fagan C.C, Everard CD, McDonnell K. (2011). Prediction of moisture, calorific value, ash and carbon content of two dedicated bioenergy crops using near-infrared spectroscopy. *Bioresour Technol*; 102:5200–6.
- Fasina O. O. (2007). Physical properties of peanut hull pellets. *Bioresource Technology*, 99, 1259-1266.
- Gabbard, W. D, & Gossman, D. (1990). Hazardous waste fuels and the cement kilns – The Incineration Alternative. *ASTM Standardization News*, September 1990, 10th March 2011, <http://gcisolutions.com/HWF&CKS.htm>
- Gemechu B. (2009). Efforts at promoting, branding Ethiopia’s coffee, *The Ethiopian Herald*, 19 May 2009.
- Giddings, D.; Eastwick, C.N.; Pickering, S.J. and Simmons, K. (2000). Computational fluid dynamics applied to a cement precalciner. *Proc. Instn. Mech. Engrs*, 214:A.
- Gillespie, G.D.; Everard, C.D.; Fagan, C.C.; McDonnell, K.P. (2013). Prediction of quality parameters of biomass pellets from proximate and ultimate analysis. *Fuel*, 111, 771–777.
- Hansen, M., Jein, A., Hayes, S. and Bateman, P. (2009). *English Handbook for Wood Pellet Combustion, Pellet Atlas*, Muenchen, Germany, 2009.
- Hendriks, C.A., Worrell, E., de Jager, D., Block, K., & Riemer, P. (1998). Reduction of Greenhouse Gases from the Cement Industry. IEA GHG Paper presented at GHGT-4 Interlaken, Switzerland.

- Henrich E., Stahl R., Gehrmann, H.J., Vodegel S., Koch M. (2014). Definition of a standard biomass. Forschungszentrum Karlsruhe GmbH. Available at del_sp2_wp1_2-1-1_05-01-10-fzk%20(1).pdf
- Hewlett, P.C. (2004). LEA's Chemistry of Cement and Concrete. (Fourth Edition). Elsevier Butterworth-Heinemann.
- Holt G. A., Blodgett T.L., Nakayama F.S. (2006). Physical and combustion characteristics of pellet fuel from cotton gin by-product by select processing treatments. *Industrial Crops and Products* 24: 204-213.
- Ikelle, I. I. and Chukwuma, A. (2014). Comparative Thermal Analysis of the Properties of Coal and Corn Cob Briquettes. *IOSR Journal of Applied Chemistry (IOSR-JAC)*, e-ISSN: 2278-5736. Volume 7, Issue 6 Ver. I. PP 93-97
- Intergovernmental Panel on Climate Change (IPCC) (2006). Guidelines for National Greenhouse Gas Inventories, Vol. 5 Waste.
- International Coffee Organization, (2017). World Coffee Production. Available at: <http://www.ico.org/prices/po-production.pdf>
- International finance corporation (IFC) (2017). Increasing the use of alternative fuels at cement plants: international best practice
- International Organization for Standardization. (2014a). ISO 17225-2: Solid biofuels - Fuel specifications and classes Part 2: Graded wood pellets. ISO/TC 238. Geneva, SW: ISO.
- International Organization for Standardization. (2014b). ISO 17225-6: Solid biofuels - Fuel specifications and classes Part 6: Graded non-woody pellets. ISO/TC 238. Geneva, SW: ISO.
- Japhet, J. A., Tokan, A., and Muhammad, M. H. (2015). Production and Characterization of Rice Husk Pellet; *American Journal of Engineering Research (AJER)*, Volume-4, Issue12, pp-112-119
- Jenkins B.M. and Ebeling J.M. (1985). Correlation of physical and chemical properties of terrestrial biomass with conversion Proc. *Energy from Biomass and Wastes, IX*, Institute of Gas Technology, Chicago, IL, pp. 371-400
- Kikuchi, R. (2001). Recycling of municipal solid waste for cement production: pilot scale test for transforming incineration ash of solid waste into cement clinker. *Resources, Conservation & Recycling*. 31: 137-147.

- Kiss, I. and Alexa, V., (n. d.): Short Introspections Regarding the Sawdust Briquetting as Sustainable Solution for the Environment, *Analecta*, Vol. 8, No. 2.
- Kuokkanen M., Vilppo T., Kuokkanen T., Stoor T., and Niinimäki, J. (2011) Additives in wood pellets, *BioResources Journal*, vol. 4, no. 6, pp. 4331–4355, 2011.
- Kyauta E. E., Adisa A.B., Abdulkadir L.N. and Balogun S. (2015) Production and Comparative Study of Pellets from Maize Cobs and Groundnut Shell as Fuels for Domestic Use. *American Journal of Engineering Research (AJER)* Volume-4, Issue-1, pp-97102
- Lechtenberg D. (2008). *Alternative Fuels in Developing Countries*, World Cement.
- Lewandowski I, Kicherer A. (1997). Combustion quality of biomass: practical relevance and experiments to modify the biomass quality of *Miscanthus x giganteus*. *Eur J Agron*; 6:163–77.
- Mackes K., and Lightburn C. (2003) Evaluating the use of green wood chips processed from small diameter trees As an alternate fuel for making cement, *Forest Products Journal*, Vol. 53, No. 4
- Mani S., Tabil L.G., Sokhansanj S. (2006). Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. *Biomass & Bioenergy*, 30, 648-654.
- McKendry, P. (2002). Energy production from biomass (part 1): overview of biomass. *Bioresource Technol.*, 83: 37–46
- Mhilu C.F. (2014). Analysis of energy characteristics of Rice and coffee husk blends. Hindawi publishing corporation. ISRN chemical engineering.
- Miranda.T , Montero I., José Sepúlveda F., Arranz J.I., Rojas C.V., and Sergio Nogales S (2005). A Review of Pellets from Different Sources. *Materials* 2015, 8, 1413-1427; doi:10.3390/ma8041413.
- Mohan, D. P. (2006). Pyrolysis of wood/biomass for bio-oil: a critical review". *Energy Fuels*, 848–889.
- Mokrzycki E., Uliasz-Bochenczyk A' and Sarna M. (2003). Use of alternative fuels in the Polish cement industry, *Applied Energy*, 74, 101-111
- Montenegro Camacho Y.S., Bensaid S., Ruggeri B., Restuccia L., Ferro G., Mancini G. and Fino D. (2016). Valorisation of by-Products/Waste of Agro-Food Industry by the Pyrolysis Process. *Journal of Advanced Catalysis Science and Technology*, 3 (1). Pp:1-11

- Morten T. H., Anna R.J., Sandra H. and Patrick B. (2009). English handbook for wood pellet combustion
- Murray, A, & Price, L. (2008). Use of Alternative Fuels in Cement Manufacture: Analysis of Fuel Characteristics and Feasibility for Use in the Chinese Cement Sector, Ernest Orlando Lawrence Berkeley National Laboratory, 10 March 2011 <http://ies.lbl.gov/iespubs/LBNL-525E.pdf>
- Nicholls D., Monerud R., and Dykstra D. (2008). A synthesis of biomass utilization for bioenergy production in the Western United States, United States Department of Agriculture Forest Service General Technical Report, PNW-GTR-753, May 2008
- Nuortio, T., Kytöjoki, J., Niska, H., Braysy, O. (2006). Improved route planning and scheduling of waste collection and transport. *Expert Syst. Appl.* 30 (2), 223–232
- Obernberger, I., Thek, G. (2004). Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass Bioenergy*, 27, 653–669.
- Odunayo A.R., Omoniyi P., Leslie P., Olorunfemi O. (2016). Comparative chemical and trace element composition of coal samples from Nigeria and South Africa. *American Journal of Innovative Research and Applied Sciences* 2 (9), 391-404
- Olmo, I.F., Chacon, E, & Irabien, A. (2001). Influence of lead, zinc, iron (III) and chromium (III) oxides on the setting time and strength of Portland cement. *Cement and Concrete Research*. 31: 1213 – 1219. Comparative Chemical and Trace Element Composition of Coal Samples From Nigeria and South Africa
- Paula et.al. 2011. Characterization of residues from plant biomass for use in energy generation. *Cerne,Lavras*, 17(2), pp.237-246
- Pellet Fuel Institute. (2011). Standard specification for residential/commercial densified fuel. Seattle, WA: PFI.
- Poddar, S.; Kamruzzaman, M.; Sujan, S. M. A.; Hossain, M.; Jamal, M. S.; Gafur, M. A. and Khanam, M. (2014): Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties:Higher heating value. *Fuel*, 131, 43–48.
- Poddar, S.; Kamruzzaman, M.; Sujan, S.M.A.; Hossain, M.; Jamal, M.S.; Gafur, M.A.; Khanam, M. Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. *Fuel* 2014, 131, 43–48.

- Ryu C., Finney K., Sharifi V. N., and Swithenbank, J. (2008). Pelletised fuel production from coal tailings and spent mushroom compost-Part I Identification of pelletisation parameters. *Fuel Processing Technology* 89: 269-275.
- Sánchez, E. A., Pasache, M. B. and García, M. E. (2014). Development of Briquettes from Waste Wood (Sawdust) for Use in Low-income Households in Piura, Peru; Proceedings of the World Congress on Engineering, Vol II, WCE 2014, London, U.K.
- Saint-Jean, S.M., Jons, E, Lundgaard, N, & Hansen, S. (2005). Chlorellestadite in the preheater system of cement kilns as an indicator of HCl formation. *Cement and Concrete Research*, 35: 431 – 437.
- Smidth F.L. and Co. (2000). Dry process kiln systems, technical brochure.
- Singh H., Sapra P.K., and Sidhu B.S. (2013). Evaluation and characterization of different biomass residues through proximate and ultimate analysis and heating value. *Asian journal of engineering and applied technology*, 2(2), pp. 6-10
- Taylor, M., Tam, C., Gielen, D. (2006). Energy Efficiency and CO₂ Emissions from the Global Cement Industry. Paper prepared for the IEA-WBCSD workshop: Energy Efficiency and CO₂ Emission Reduction Potentials and Policies in the Cement Industry, IEA, Paris, 4–5
- Thek, G. and Obernberg I. (2010), *The Pellet Handbook: The Production and Thermal Utilization of Biomass Pellets*, Earthscan, London, UK, 2010.
- Tokan, A., Muhammad, M. H., Japhet, J. A. and Kyauta, E. E. (2016). Comparative Analysis of the Effectiveness of Rice Husk Pellets and Charcoal As Fuel For Domestic Purpose, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 13(15), Ver. VI, PP 21-27
- Tokheim L.A. (2007). Carbon Dioxide Emission Reduction By Increased Utilization Of Waste-Derived Fuels In The Cement Industry, Telemark University College, Faculty of Technology, Porsgrunn, Norway UNDP / World Bank Energy Sector Management Assistance Programme (ESMAP), 1986, Agricultural Residue Briquetting Pilot Projects for Substitute Household and Industrial Fuels, Volume 1 – Technical Report, DEC
- Xing Yang, Hailong Wang, Peter James Strong, Song Xu, Shujuan Liu, Kouping Lu, (2017). Thermal Properties of Biochars Derived from Waste Biomass Generated by Agricultural and Forestry Sectors. *Energies*.
- Yisehak Seboka, Mulugeta Adamu Getahun, Yared Haile-Meskel. (2009). Biomass energy for cement production: opportunities in Ethiopia. New York, USA: UNDP.