ASSESSING OPTIMAL RATE OF SOLID WASTE FUEL SUBSTITUTION: THE CASE OF NATIONAL CEMENT FACTORY, DIRE DAWA, ETHIOPIA

M.Sc. THESIS

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APPROVAL SHEET I

This is to certify that the thesis entitled ‘‘**Assessing Optimal Rate of Solid Waste Fuel Substitution: The Case of National Cement Factory, Dire Dawa, Ethiopia**’’ is submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Renewable Energy Utilization and Management, Wondo Genet College of Forestry and Natural Resource, and is a record of original research carried out by **Andualem Tesfaye** Id. No. **MSc/REUM/R003/09**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistances and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

Solomon Tesfamariam (Ph.D.)	____________________	____________
Name of Major Advisor	Signature	Date

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STATEMENT OF AUTHOR

I hereby declare that this thesis is my original work and has not been presented for a degree in any other University.

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Date: ____________________

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LIST OF ACRONYMS AND ABBREVIATION

AF	Aluminum Factor
Al_2O_3	Aluminum Oxide
APEIB	Agricultural Product Exporter & Importer Business
BoFED	Bureau of Finance and Economic Development
BTU/Lb	Britain Thermal Unit per Pound
C	Carbon
CaO	Calcium Oxide
CKD	Cement Kiln Dust
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CB	Construction Business
C2S	Di-calcium silicate
C3S	Tri-calcium silicate
C4AF	Tetra-calcium aluminate ferrite
C3A	Tri-calcium aluminate
CRGE	Climate Resilient Green Economy
CSA	Central Statistics Authority
CSI	Cement Sustainability Initiative
DDA	Dire Dawa Administration
DDCA	Dire Dawa City Administration
EB	Education Business
FDRE	Federal Democratic Republic Of Ethiopia
Fe_2O_3	Iron Oxide
GHG	Greenhouse Gas
GJ	Giga Joule
H	Hydrogen
HB	Health Business
HHV	Higher Heating Value
HRB	Hotel & Restaurant Business

IFC	International Finance Corporation
Kcal/kg-cl	Kilo Calories per Kilogram of clinker
Kj/kg-cl	Kilo Joule per Kilogram of clinker
Kwh	Kilo Watt Hour
LHV	Lower heating Value
LSF	Lime Saturation Factor
NCSC	National Cement Share Company
M	Mass
m.a.s.l	Meter Above See Level
MC	Moisture content
MgO	Magnesium Oxide
MIB	Manufacturing Industry Business
Mt CO_2e	Million Ton of Carbon Dioxide Equivalent
Mt	Million Ton
N	Nitrogen
NCV	Net Calorific Value
NOx	Nitrogen Oxides
O	Oxygen
OPC	Ordinary Portland Cement
PPO	Public and Privet Office
S	Sulfur
SF	Silica Factor
SiO_2	Silicate
SOx	Sulfur Oxides
SWM	Solid waste material
TIO	Trade Industry Office
TED	Thermal Energy Demand
TPD	Ton Per Day
TSR	Thermal Substitution Rate
TUMB	Transport, Utility & Maintenance Business
UC	Unit Cost

UNEP	United Nations Environment Program
VOC	Volatile Organic Compound
WBCSD	World Business Council for Sustainable Development
WSRB	Wholesales & Retailer Business
Ω	Mass fraction
XRD/F	X-Ray Diffraction or Fraction

ABSTRACT

As part of economic and environmental solution, cement industries massively involved on fuel and material substitution. Due to its economic and environmental performance, solid waste has been largely preferred for fuel and raw material substitution. But no cement facilities operated in Ethiopia still engaged on yet. To this effect, this research intended to find best possible strategy for solid waste fuel substitution in cement kiln: for case specific cement plant of National Cement Share Company (NCSC) and solid waste material (SWM) generated from Dire Dawa City Administration (DDCA). Accordingly, the research investigated the potential and performance of solid waste resource along with operational restriction and product specification. This information was thus used for evaluating optimal rate of solid waste fuel substitution. Data for operational restriction and product specification of the cement plant were collected through interview & document review. Whereas, the potential & performance of solid waste resource were determined through waste quantification and characterization surveys conducted at point of waste stream. Samples were collected through interview and observation of 180 households and business units from systematically selected two urban kebeles. Observations were made based on weight recording and visual inspection after sorting. Data from waste surveys were analyzed using descriptive statistics. The result revealed that the daily waste generation rate was found about 262ton. Of which the amount of waste components, which is suitable for material and energy recovery in cement plant, accounted for 39.86% (68.77ton/day). The empirical analysis of heating value for net calorific value on dry base was found about 19500kJ/kg. Accordingly, an optimization model with linear problem was developed to find optimal rate of solid waste substitution with maximum economic benefit subject to operational and quality restriction constraint. Micro-soft Solver was used to optimize. The model result showed that at 13% substitution rate: clinker production cost-which is a function of cost of fuel and raw material-was minimized; quality and operational restriction was satisfied. Effects of 13% substitution on emission and combustion air demand were also evaluated. The results revealed that emission (CO2 and SO2) and combustion air demand was reduced by marginal fraction. This indicate that it would be economically as well as environmental feasible for NCSC to substitute 13% SWM generated from DDCA without even affecting the product quality and operation.

Key Words: *waste quantification and characterization, material and energy recovery, solid waste fuel substitution, cement plant, operational restriction, product specification, Dire Dawa City*

1. INTRODUCTION

1.1. Background

Cement demand and production are increasing all over the world. Global production was projected to grow from 2,540 Mt in 2006 to 4,380 Mt in 2050 (WBCSD, 2014). In Ethiopia, it was also projected to increase from 2.7 Mt in 2010 to 65 Mt in 2030 (FDRE, 2010). The increase in production is associated with a significant increase in the absolute energy use and CO2 emissions of the industry. This is due to the fact that, cement industry is an energy-intensive industry with thermal energy consumption of 3-4.2GJ per ton of clinker (WBCSD, 2014) and electric energy consumption of 90-150KWh per ton of cement (IFC, 2017). Energy related cost, typically fossil fuel and electricity, accounts for 30-40% of operational costs (GTZ, 2006). About 5% of the global anthropogenic CO_2 emissions (WBCSD, 2014) and 1.5% of the Ethiopia's emission (FDRE, 2010) are originated from the cement industry. Use of alternative fuel (alternatively "co-processing or fuel substitution") is widely practiced technique to improve the environmental and economic performance of cement industry. There are several alternative fuel source that can be used as fuel substitution in cement industry. Of all the alternatives, SWM perform better in terms of environmental and economic performance. The benefits achieved by SWM substitution as coined by several literatures include: fuel cost saving between 50-70% (GTZ, 2006; WBCSD, 2014; IFC, 2017); reducing CO_2 emission reduction up to 1.6 kg of CO2 per kg of utilized SWM (Genon and Brizio, 2008) compare to coal usage, and reducing landfill burden or avoiding new investment in landfill facilities (Del Zotto *et al.*, 2015). Depend on the operational condition, and chemical property of waste material, it can also reduce emission of NOx and SOx (Genon and Brizio, 2008). EU countries (such as: Germany, Belgium, Poland and Switzerland) replaced Over 60% of fossil fuel, which can help to conserve nonrenewable fossil fuel resources (GTZ, 2006; WBCSD, 2014; IFC, 2017).

SWM substitution is referred to any processed solid waste material that can replace part of the fuel and raw material needed for the production of cement, whether it is used for thermal energy or material recovery. As reported in several literatures, the solid waste material that can be used and/or allowed as fuel substitution comprises household waste, municipal waste, industrial waste, hazardous waste, agricultural residue, construction waste and others (GTZ, 2006; WBCSD, 2014; IFC, 2017).

1.2. Problem and Justification

Due to its economic and environmental performance, SWM substitution has been largely practiced globally. For instance, EU countries replaced over 60%, which is the highest rate in the world (GTZ, 2006 and IFC, 2017). Although the benefit appeared to be highly positive particularly to cities and cement companies, no real actions has been materialized in Ethiopia so far.

As part of emission reduction strategy, the government of Ethiopia, in its plan of Climate Resilience Green Economic Development Strategy (CRGE), has set 20% fuel substitution in all cement industry by 2030. Despite the fact that SWM appeared to be relatively economic and environmentally friendly, the government strangely preferred to substitute agricultural biomass over SWM. Although SWM substitution is relatively sustainable in several of countries, there are still constraints coupled with the availability of waste, transportation and storage facility, suitability of the exciting kiln technology, and characteristics of the waste (GTZ, 2017 and CEMBUREAU,1999).

On the other hand, reusing the SWM as fuel and raw material substitution in cement manufacturing provides energy and material recovery opportunity for municipalities waste management which can be seen as win–win situation for cement companies and municipalities. No cities in Ethiopia except Addis Ababa has possessed waste to energy recovery technologies for municipal solid waste management. One of the major characteristics of the cement kiln that makes it perfect for solid waste and/or hazardous waste management rather than any waste to energy recovery technologies is its high temperature (1200-17000C) and long residence time (4-6s), the high thermal capacity, the alkaline environment and the minimum amount of waste generated (CEMBUREAU,1999).

Due to these reason this research was carried out to look for answer while questioning “why SWM does not have attention as there is big city in close proximity to cement factory”. For example: Dire Dawa City & National Cement Share Company; and Mekele City & Mesobo Cement Factory. It is off course a good opportunity for municipalities and cement companies; but, neither of them have made a single step toward the initial stage of resource assessment and feasibility study.

Axumawi (2015) has done quite the same type of research but based on *prosopis juliflora* while considering Mesebo Cement Factory, which is located in Mekele City. The resource is found in Afar Regional State, which is 580km far from Mesebo Cement Factory. The author’s finding thus highlight that the economic and environmental implication is comparatively more at 40% substitution rate. But, several researches have been done in other countries. For instance: Rahul Baidya *et al*. (2016) examine the effectiveness of SWM substitution in cement plants as an effective energy and material recovery; Kaddatz *et al. (*2013) and Azad Rahman *et al. (*2014) investigate the suitability and performance of the plant and thus predict the energy efficiency and emission reduction rate based on fuel mix optimization; while Joseph and Obodeh (2016) predict optimal rate of SWM substitution which give rise to maximum benefit from cement product and environmental quality perspective based on cost benefit calculation, Hiromi *et al.*(2014) examines the extent of various type of SWM substitution rate without severely changing the process condition and product quality based on mass and energy balance model.

The problem of finding optimal rate of alternative fuel substitution taking into account of operational restriction and environmental limit is discussed in detail with case specific problem in paper of Ioannis *et al*. (2011). Where the decision of optimal rate of multiple alternative fuel with different raw material is computed based on a Mixed Integer Linear Program problem. Therefore, the cost of raw materials is minimized and several operational constraints are satisfied. Similarly, Carpio *et al.* (2008) present an optimization based framework for the selection of both raw material and fuels that include one alternative fuel, namely tyre derived fuel. Where the decision of best possible solution is evaluated based on linear problem for raw material and fuel mix and the result agreed with Ioannis *et al*. (2011). A more systematic treatment is presented by Westerlund (1989), where the selection of the raw materials is based on a nonlinear programming problem, accordingly the cost of raw materials is minimized and several operational constraints are satisfied.

However, finding the optimal rate of SWM fuel substitution is as such plant and resource specific and has no specific standard as it determined by several factors. This was considered to be the knowledge gaps that is trying to be answered by this paper. Beside to this, In Ethiopia, only a single study which is a rather related to the general term of alternative fuel substitution have been conducted. But, there is no research specific to solid waste fuel and material substitution using for municipal waste management, emission reduction and economic solution. However, this study therefore tries to find the best possible strategy for solid waste fuel substitution, with the aim of providing plant and site specific information that will aid the formulation of solid waste fuel and material substitution strategy for green economy development policy.

1.3. Objective

1.3.1. General objective

The main purpose of this study was to investigate the optimal rate of solid waste material and fuel substitution for maximum economic benefit while satisfying the product specification in the case of National Cement Share Company's cement plant and Dire Dawa City Administration's Solid Waste material. To this effect, both municipal solid waste and cement plant were subject to the research inquiry.

1.3.2. Specific objective

The research was designed based on addressing the following specific objection:

- To assess the household & non-household solid waste generation rate in Dire Dawa City
- To assess the combustible and non-combustible fraction of solid waste component in Dire Dawa City
- To assess the physical and chemical characteristics of combustible fraction of the solid waste material in Dire Dawa City
- To assess operational and product specification of National Cement Share Company's cement plant
- To evaluate the optimal rate of solid waste material and fuel substitution assuming the Dire Dawa city's SWM and NCSC's cement plant

1.4. Research question

The study conducted attempted to answer the following research questions:

- How much solid waste is generated from household and non-household generators located in Dire Dawa City?
- What are the fraction of combustible and non-combustible solid waste components in Dire Dawa City?
- What are the physical and chemical characteristics of the combustible solid waste fraction in Dire Dawa City?
- What are the operational and product specification of National Cement Share Company's cement plant?

- What is the optimal rate of solid waste material and fuel substitution assuming NCSC's cement plant and the Dire Dawa city's SWM?

1.5. Significance of the study

Information generated from this study may help to provide valuable information to decision or policy makers who may formulate policies that promote the use and benefit of solid waste fuel substitution for carbon reduction commitment, solid waste management, job creation, air quality improvement and foreign currency saving.

Any cement companies who want to meet their corporate responsibility are expected to in place a process or system that integrate social and environmental concern into their business operation and core strategy. So this research indicates project idea that can be considered as corporate social and environmental initiative, which is a win-win solution for all parties. That means the cement plat can receive a reliable local supply of fuel or material that replaces natural resources and the community can be benefited from job opportunity and waste free environment, and the municipal can be benefited in providing sustainable solid waste management service and solution while saving the large capital investment for incinerator and waste-to-energy plants establishment.

Beside this, this study demonstrates how sloid waste material and fuel substitution in cement industry can be applied from resource assessment to feasibility study stage. Other researchers and institution who devised solid waste management plan in DDA may also use the findings of this study for planning of solid waste management system or for designing waste to energy facility, compost project and landfill design.

1.6. Scope and Limitation of the Study

1.6.1. Scope of the study

Solid waste material covered by this research limited to solid waste originated from household and commercial, service provider, manufacturing, transport and constriction sectors. Geographically, this study was limited to urban areas of DDA, Ethiopia. Conceptually, this research was limited on optimal rate of alternative fuel and material substitution for maximum economic benefit while satisfying product quality and operation restriction. Theoretically, the research was based on the ideas of solid waste material and energy recovery using cement kiln as thermal treatment for solid waste management, emission reduction and economic solution. Methodologically, this study was employed mixed research methods. In terms of time**,** this research used cross-sectional waste data generated on specific season of the year

1.6.2. Limitation of the study

This research utterly aimed on municipal solid waste substitution and did not include agricultural waste and other liquid and gaseous fuel type such as sludge, waste oil and landfill gasses. This research did not examine the feasibility of SWM substitution for other cements facilities operated in DDA. In order to identify the elemental and chemical property of the solid waste, the research did conduct proximate and ultimate analysis. When optimizing, the study did not consider other economic factor such as carbon reduction revenue, avoided landfill investment cost, and environmental & operation factors such as reduction of mass of air requirement, and SOx and NOx emission. Longitudinal waste data were not used for this study although waste generation varied by seasonal factors.

2. LITERATURE REVIEW

2.1. Solid waste fuel substitution and co-processing

According to Cement Sustainability Initiative Guideline (WBCSD, 2014), co-processing or Solid waste fuel substitution is defining as: the use of suitable waste materials in manufacturing processes as energy and resource recovery.

According to GTZ (2006) co-processing means the partial substitution of raw material and primary fuel by waste, biofuel, agricultural by-product and biomass. In general, it is a recovery of energy and material from waste material and other Agricultural by-product.

2.2. Status of solid waste fuel substitution

Use of waste as alternative fuels in the cement manufacturing industry emerged during the late-1970s (Anton *et al.,* 2012) and has been practiced so far, especially in developed countries/regions such as Europe, Japan, the United States, and Canada (GTZ, 2006; Genon and Brizio, 2008).Waste co-processing Fossil fuels, such as coal and petroleum coke, have traditionally been used as energy sources; however, these fuels are increasingly being substituted with alternative fuel, typically residue-based sources (e.g., sorted municipal solid waste, tires, and waste wood). GTZ (2006) also reported that waste co-processing has been practiced for more than 40 years, especially in developed countries/regions such as Europe, Japan, the United States, and Canada.

The IFC (2017) report summarized the alternative fuel substitution rate in the cement sectors of selected countries during the period 2010–2012, see the following Table 1.

Table 1: Alternative fuel substitution rates in selected countries and regions

Country	Substitution Rate (%)
Germany	65
Belgium	60
Switzerland	52.8
Poland	45
Sweden	45
France	30
Spain	22.4
United Kingdom	19.4
Japan	15.5
USA (2003)	25

Source: Sofies (2012), cited by IFC (2017). The source for USA is GTZ (2006)

In the EU, co-processing represented nearly 59% of the thermal energy needs of the cement industry. EU countries mostly Germany, Belgium, Poland and Switzerland are the leading countries in the world by substituting over 50%, yet the current subsidy, policy support and increased knowledge on the area is creating a good opportunity. According to the latest statistics Data from GNR data base (2016), alternative fuel use based particularly Solid waste material in Africa reached 1.4%. North African Country account for 90% with Egypt 35%. There are seven cement factories already operating in Ethiopia and around 39 new factories are at various stages of investment, planning and development. When the planned plants are completed there will be approximately 46 cement factories in total (UNDP, 2009). But no factory engaged on co-processing.

Many research and international experience suggested that no single alternative fuel as such meet the entire thermal demand of cement manufacturing. However, a mix of different alternative fuels can achieve that goal. For instance: as displayed in Figure 1, EU countries uses varieties of wastes (CEMBUREAU, 2015) of which plastic wastes dominate by 37% use, industrial solid waste -18%, used tyres -15%, biomass including animal bone - 13% and others.

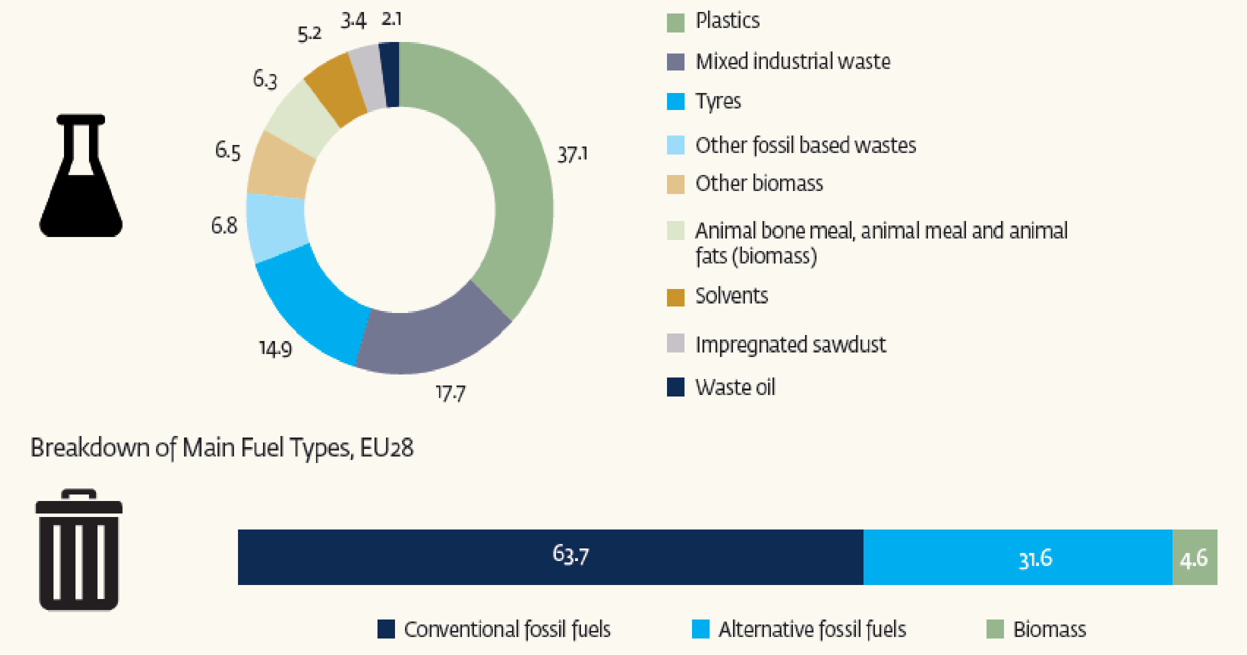


Figure 1: Alternative fuels & main fuel types in the EU (CEMBUREAU, 2015)

2.3. Solid waste fuel substitution impact and barriers

In his conclusion, Rahul *et al.* (2016) outlined that the advantages of co-processing include: reduce burden in landfill and improve waste management; reduce CO_2 and air emission; reduce cost of clinker production due to low cost fuel substitution; preserve fossil fuel resources as a result of lower use; avoid waste residue resulted from combustion process i.e. no ash, slag, CKD exist, destroy all hazardous substances due to high temperature, long gas residue time, alkali combustion material, counter flow principle and oxidizing atmosphere

2.3.1. Environmental and health impact of solid waste substitution

The use of SWM implies a reduction of the use of fossil fuels in cement kilns (Mustefa 2013; Joseph and Obodeh, 2015). Consequently, many studies verify a net reduction of between -1.02-1.36 in CO_2 emissions in comparison to fossil fuel combustion (Jenkins et al.,1998; Demirbas, 2003; IPCC, 2006). The same studies also reported that the use of SWM in cement kilns reduces methane emissions, the rationale being that using SWM as an alternative fuel avoids landfilling waste, which is a source of methane emissions (methane is approximately 20 times more effective at trapping heat in the atmosphere than carbon dioxide).

Several researchers, for example Mustefa (2013) Joseph and Obodeh, (2015), stated that emission of air pollutants particularly NOx and SO_2 emission is reduced, when SWM is being fired instead of fossil fuels. However, Hiromi *et al. (*2014) and Anton *et al.* (2012) argued that emissions of NOx and SO_2, while firing SWM, is relatively depend on either of the composition of the fuel or the operation procedure. They did examine the solid waste composition, in particular nitrogen, sulfur, and chlorine content, and concluded that the formation of nitrogen oxides is related to the temperature of the kiln, the residence times, the types of burners, and the amount of nitrogen in the fuel. Hence, Nitrogen content is linked to the formation of NOx and the study showed that the content of nitrogen in the waste is lower than in fossil fuels, meaning that NOx emissions from SWM are lower than for fossil fuels, all other things being equal. This study found a similar situation in terms of sulfur content and chlorine. The alkaline conditions (Na, K, Ca, Mg) and the intensive mixing favor the absorption of volatile components from the gas phase. This internal gas cleaning results in low emissions of components such as SO_2, HCl, and, heavy metals (with the exception of mercury and thallium). The combustion of chlorinated waste is neutralized by forming into calcium chloride (CaCl2), sodium chloride (NaCl) and potassium chloride (KCl).

However, the use of chlorinated SWM can create problems. Due to the fact that chlorine introduced to the kiln system in the presence of organic material may cause the formation of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). In general, the composition of the fuel used in kilns, can influence the pollutant emissions.

Failing to meet the operational, environmental & waste requirement, and operational control procedure (see section 2.6) can result in emission of high volume of particulate matter and gases pollutant which may contaminate the ambient air quality. Exposure of employee and local communities to these emissions may result series health risk (IFC, 2014).

2.3.2. Economic Impact of solid waste substitution

The cost of energy for SWM feeding is lower than fossil fuels feeding (GTZ, 2006; WBCSD, 2014; IFC 2017). Depending on the rate of substitution and waste material used; SWM substitution can save cost of energy between 50-70%. However, due to the lower energy content in SWM, the cost per heat unit can be higher than fossil fuels as for SWM compared with coal. Substitution of solid waste in kiln system requires additional investments in the coal feeding system of the plant in order to facilitate the process of co-processing such as kiln and equipment upgrades, and waste pre-processing materials acquisition and transportation. It is also requiring additional operation cost when waste enrichment appeared to be necessary as it is characterized by lower calorific value, higher volume or size, non-uniform chemical composition than coal. It is also affected by sustainable supply of the resource, performance testing, continuous emissions monitoring systems, sampling and testing of materials, and operation, health and safety (Ali *et al*,2012):

2.3.3. Barriers of solid waste substitution

Key barriers of co-processing, as point out by Ali *et al.* (2012), includes lack specific regulations and standards particularly for waste co-processing, lack of supportive policy and incentive, community resistance because lack of awareness on the impact, high production cost of SWM compare to landfilling, lack of infrastructure for waste segregation, transportation and pre-processing, lack human capacity (highly qualified experts to install and set up the equipment and trained personnel to operate the equipment).

2.4. Basics of cement production & rational for SWM substitution

Cement demand and production are increasing all over the world. Global production is projected to grow from 2,540 Mt in 2006 to 4,380 Mt in 2050. (WBCSD, 2014). In Ethiopia, it is projected to increase from 2.7 Mt in 2010 to 65 Mt in 2030 (FDRE, 2010).

Ordinary Portland Cement (OPC) is one of several types of cement being manufactured throughout the world in general (CEMBUREAU, 1999) and in Ethiopia specifically (UNDP, 2009).

2.4.1. Cement production and process

The two basic methods to produce cement are the wet and dry manufacturing processes. The main difference between wet and dry process is the mix preparation method prior to burning clinker in the kiln. In the wet process water is added to the raw materials to form a raw thick slurry whereas the dry process is based on the preparation of a fine powdered raw meal by raw materials grinding and drying (CEMBUREAU, 1999 and ACCA21,2009).

Portland cement is produced by intergrading clinker with a few percent of gypsum or anhydrite (calcium sulphate) acting as a set regulator. Clinker is produced from a mixture of raw materials containing lime ($CaCO_3$), silica (SiO_2), alumina (Al_2O_3), iron (Fe_2O_3) and Sulphur trioxide (SO_3). Magnesium (MgO) and other Oxide elements are present in small quantities as an impurity associated with raw materials. Primary raw materials usual includes limestone, chalk, marl and shale or clay. In addition, bauxite, iron ore, blast furnace slag or foundry sand are used as correctives of raw mix. The ash from fuel used and other power plant source also used for material substitution (EIPPCB, 2013, CEMBUREAU, 1999 and IFC, 2007).

The basic chemistry of the cement manufacturing process begins with the decomposition of calcium carbonate ($CaCO_3$) at about 900°C to calcium oxide (CaO, lime) and liberated gaseous carbon dioxide (CO_2); this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at a high temperature (typically 1400–1500°C) with silica, alumina, and ferrous oxide to form the silicates, aluminates, and ferrites of calcium which comprise the clinker. The main chemical composition in clinker chemistry at this stage are silicates (in the form of Alite ($3CaO \times SiO_2$ or C3S) at 50-70% and Belite ($2CaO \times SiO_2$ or C2S) at 15-30%), aluminates ($3CaO \times Al_2O_3$ or C3A) at 5-10% and ferrites ($4CaO \times Al_2O_3 \times Fe_2O_3$ or C4AF) at 5-15%. The clinker is then ground or milled together with gypsum (SO_3) and other additives to produce cement. Gypsum is added at the grinding stage to retard the setting time of the finished cement (EIPPCB, 2013 and CEMBUREAU, 1999).

figure 2 illustrate the production process of cement. It often consists of common steps: quarrying, preparation of raw materials, clinkering (raw material drying-calcination-clinkering-cooling), grinding clinker into cement, blending with additive and Bagging cement (ACCA21, 2009).

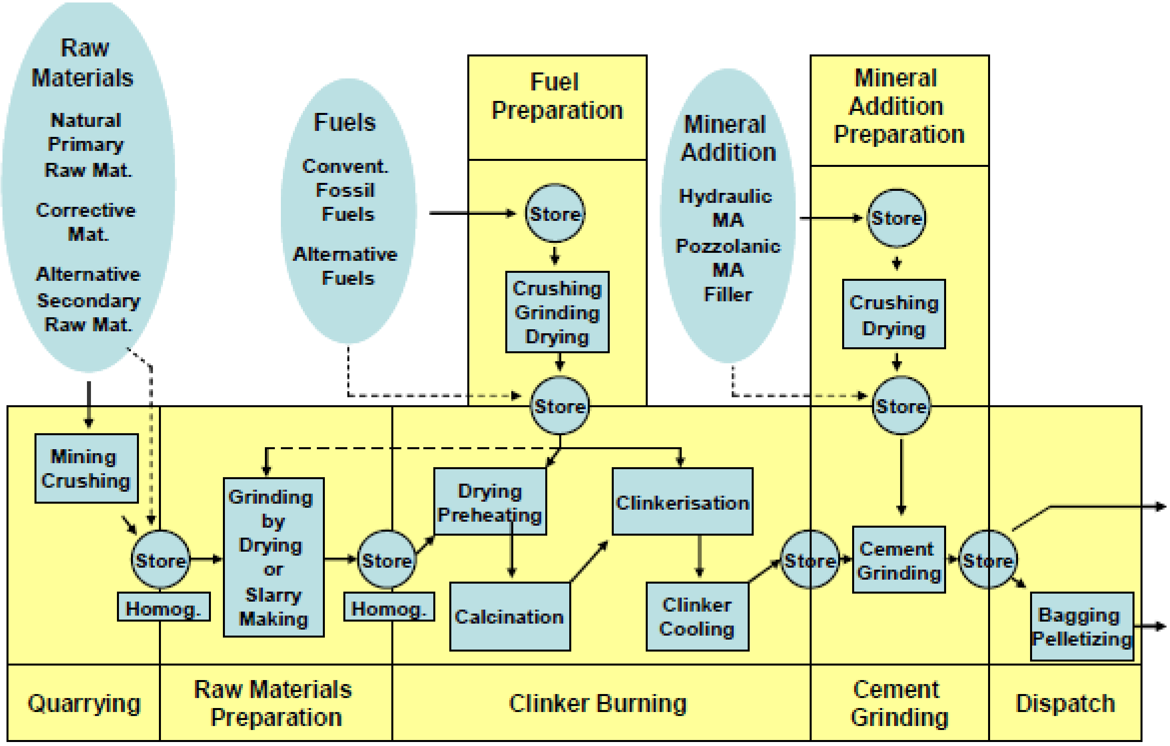


Figure 2: Simplified cement process (ACCA21,2009)

2.4.2. Emission from cement production

The main environmental concern of air emission from in the manufacture of cement are related to the dust and gaseous atmospheric emissions (EIPPCB, 2013, CEMBUREAU, 1999 and IFC, 2007). Major gaseous emissions are NOx and SO_2. Other gaseous emissions of less significance are VOCs (volatile organic compounds), CO, ammonia, HCl, and heavy metals. CO_2 as the main greenhouse gas is released in considerable quantities. Major dust emissions are $PM_{10 \text{ or } 2.5}$ (particulate matter) with a grain size of less than 10 and less than 2.5 microns in diameter respectively which can arise in solid form or as aerosols (EIPPCB, 2013, CEMBUREAU, 1999 and IFC, 2007).

Nitrogen oxides (NOx) are formed in two ways. 1) thermal NOx: part of the nitrogen in the combustion air reacts with oxygen to form various oxides of nitrogen. This is the major mechanism of nitrogen oxide formation in the kiln flam during high temperature combustion processes with long residence time. 2) fuel NOx: compounds containing nitrogen, chemically bound in the fuel, react with oxygen in the air to form various oxides of nitrogen.

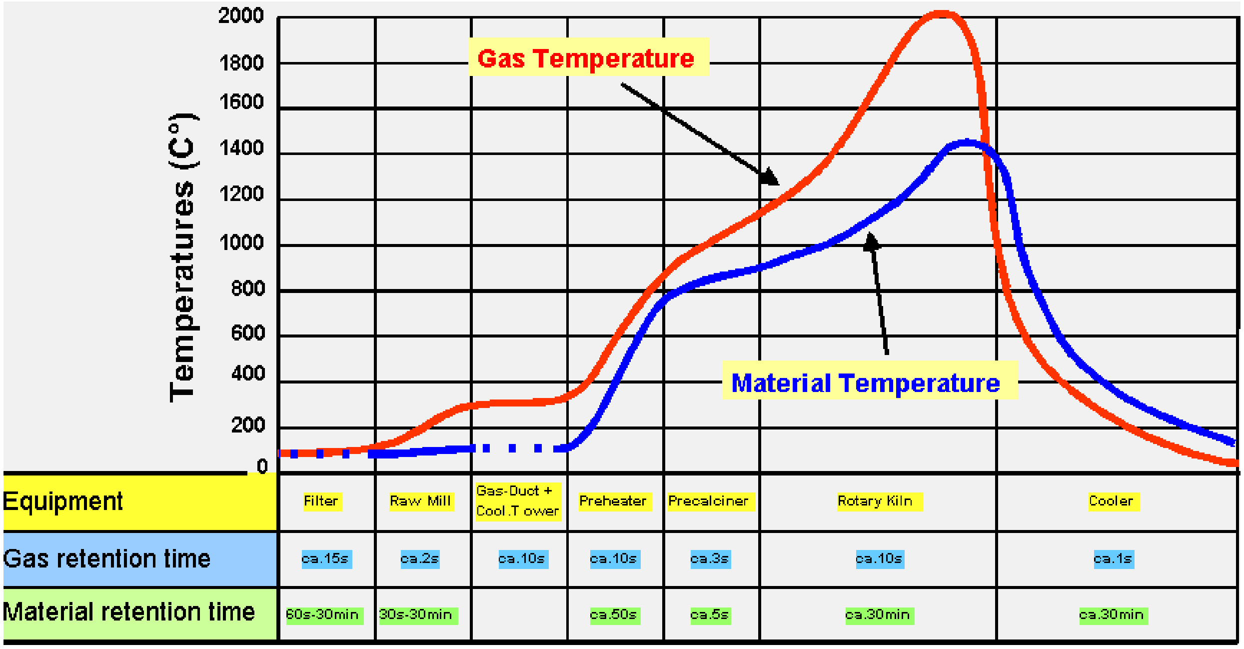
Carbon dioxide is produced by the fuel combustion ($C + O_2 \rightarrow CO_2$) and by the calcination of $CaCO_3$ ($CaCO_3 \rightarrow CaO + CO_2$)

Sulfur dioxide is produced by the fuel combustion ($S + O_2 \rightarrow SO_2$) and from raw material with high content of organic sulfur or pyrite (FeS) in the burning zone of the kiln (from sulfates, e.g. CaSO4) and oxidation of pyrite/marcasite (sulfide) and organic sulfur in the preheater or in the kiln inlet of long dry kilns.

2.4.3. Combustion characteristics & thermal zone

There are three distinct thermal zones within an operating cement plant, as illustrated in figure 3 and 4 below: drying and preheating zone (20–900^{0}C), Calcining zone (600–900^{0}C) and burning zone (clinkering zone) (1,400–1,500^{0}C).

As shown in figure 4, the material in the drying and preheating zone reaches a temperature of about 750 ^{0}C. In this zone, all water in the material is evaporated. The calcining zone is set after preheating zone. Carbon dioxide (CO_2) is driven off from the limestone material and calcium oxide (CaO) is, thus, formed. The material temperature in this zone reaches 1,000 ^{0}C. After calcination, the burning zone (also called as clinkering zone) is placed. The temperature of burning zone reaches 1,450 ^{0}C that leads chemical reactions to form partial Belite ($2CaO*SiO_2$ or C2S). Above 1,450°C a liquid phase appears and this promotes the reaction between Belite and free lime to form Alite ($3CaO \times SiO_2$ or C3S). During the cooling stage the molten or crystallization phase forms Aluminate ($3CaO \times Al_2O_3$ or C3A) at 5-10% and Ferrites ($4CaO \times Al_2O_3 \times Fe_2O_3$ or C4AF). The clinker is in a semi–liquid state at this stage, but cooled down by the grate cooler (Yukari and Sunil, 2012; CEMBUREAU, 1999).



Equipment	Filter	Raw Mill	Gas-Duct + Cool.T ower	Preheater	Precalciner	Rotary Kiln	Cooler
Gas retention time	ca.15s	ca.2s	ca.10s	ca.10s	ca.3s	ca.10s	ca.1s
Material retention time	60s-30min	30s-30min		ca.50s	ca.5s	ca.30min	ca.30min

Figure 3: Combustion characteristics in preheater-precalciner kiln (CEMBUREAU, 1999)

As shown in figure 3 above, the material and gas temperature during combustion process inside the kiln reaches 1,500 ^{0}C (Yukari and Sunil, 2012) and 2,000^{0}C (CEMBUREAU, 1999) in order to form the clinker. To achieve this clinkering temperature, combustion gas temperature in the burning zone of the kiln must generally exceed 1,700^{0}C (Yukari and Sunil, 2012) and 1,500^{0}C (CEMBUREAU, 1999). In addition, residence time of combustion gas in the burning zone of the kiln ranges from 2 to 5s that depends on the size of the kiln. The overall gas residence times during the process can reach 10s. An excess of oxygen – typically 2-3% – is also required in the combustion gases of the rotary kiln as the clinker needs to be burned under oxidizing conditions. Under the conditions prevailing in a cement kiln – i.e. flame temperatures of up to 2,000° C, material temperatures of up to 1,500° C and gas retention times of up to 10 seconds at temperatures between 1,200 and 2,000° C – all kinds of organic compounds fed to the main burner with the fuels are reliably destroyed. Figure 3 illustrates the temperature profiles for the combustion gases and the material for a preheater/precalciner rotary kiln system.

2.4.4. Clinker kiln systems or technology

Clinker production is the most energy-intensive stage in cement production. Kiln systems evaporate the inherent water in the raw meal, calcine the carbonate constituents (calcination), and form clinker (cement minerals). The main type of kiln technology used today is the dry rotary kiln.

The dry rotary kiln technology is grouped into: a) kiln without pre-heater; b) kiln with pre-heater; c) kiln with both pre-heater and precalciner see figure 4.

The first dry kiln process was developed in the U.S. and did not involve preheating. Later developments added multi-stage suspension preheaters (cyclones) or shaft preheaters. Kilns with preheating are preferred to kilns without preheating as they have a lower energy consumption. For this reason, long rotary kilns without preheating are being replaced over time. Long dry rotary kiln without preheating uses feed material with low moisture content (0.5 percent).

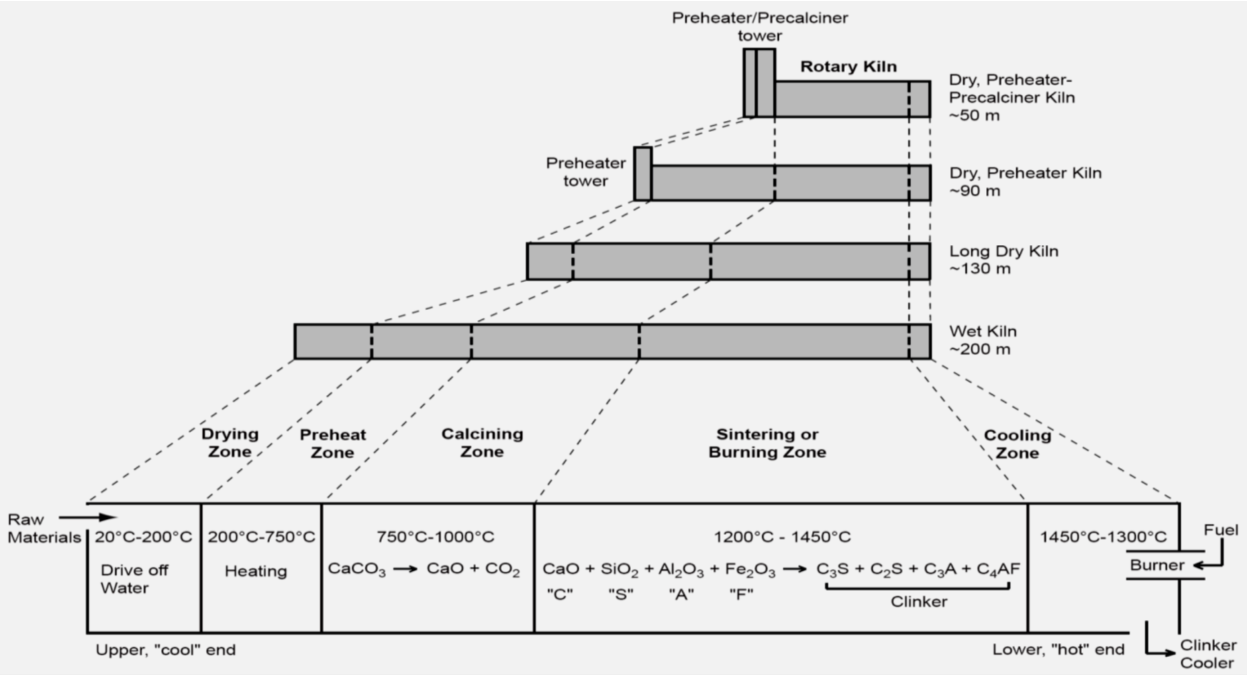


Figure 4: Type of kiln technology (ETSAP, 2010)

More recently, precalciner technology was developed in which a second combustion chamber is added between the kiln and a conventional pre-heater that allows for further reduction of kiln fuel requirements. New facilities usually include both preheating and precalciner. A preheater is a series of vertical cyclones in which the material is passed in counter-flow with exhaust gases counter-flow with exhaust gases from rotary kiln so that heat is transferred from the hot gas to the raw meal, which is therefore preheated and even partially calcinated (30%) before entering the rotary kiln. In the 1970s, a 4-stage cyclone preheater kiln (so-called suspension preheater, SP) was considered the technology of choice for dry and semi-wet processes. However, a number of different SP kilns is available. Most common SP kilns have between 4 and 6 cyclone stages. The number of stages is determined by the moisture content of the raw materials (ETSAP, 2010).

2.4.5. Energy consumption

The electricity use in cement production varies between 90 and 150 kWh per ton (IFC, 2007). According to the IFC (2007), electricity consumptions ranges from 90 to 120 kWh/t of cement. Grinding may account for a significant part of electricity consumption (up to 100 kWh/t). In a dry process, the electricity consumption share is 38% for cement grinding, 24% for raw material grinding, 22% for clinker production including grinding of solid fuels, 6% for raw material homogenization, 5% for raw material extraction and blending, and 5% for conveying, packing and loading.

Cement manufacture is an energy-intensive industry in which energy is mainly consumed by kiln system for clinker production. The heat requirements of a cement kiln plant depend, to a major extent, on the technology used. In the modern dry process with a suspension preheater and precalciner, the specific heat consumption ranges from 3-4.2GJ per ton of clinker depending on the various operational and technical parameters of the process (WBCSD, 2014). A wide range of solid, liquid and gaseous fossil fuels is used to provide energy for raw materials drying and preheating, and for chemical reactions that sinter the raw materials into clinker in the kiln. The most used solid fossil fuels were petcock and coal. Oil and natural gas are used to a lesser extent as they are in general more expensive. Primary fossil fuels are often replaced by waste derived fuels, such as: wood, paper, cardboard; textiles; plastics; RDF; rubber / tyres; industrial sludge; municipal sewage sludge; animal meal, fats; coal, carbon waste; agricultural waste; solid waste (impregnated sawdust); solvents and related waste; oil and oily waste.

2.4.6. Fuel feed points and kiln firing

The fuel introduced via the main burner produces the main flame with flame temperatures of around 2000°C. For process optimization reasons, the flame has to be adjustable within certain limits. In a modern indirectly fired burner, the flame is shaped and adjusted by the primary air (10–15% of total combustion air). As GTZ (2006) point out, the potential feed points for supplying fuel to the kiln system are via:

- The main burner at the rotary kiln outlet end
- A feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel)

- Secondary burners to the riser duct
- Precalciner burners to the precalciner
- Feed chute to the precalciner (for lump fuel)
- Mid kiln valve in the case of long wet and dry kilns (for lump fuel)
- The end of the Lepol grid.

2.4.7. Characteristics of cement kiln as a solid waste management option

One of the major characteristics of the cement kiln that makes perfect for solid waste management as highlighted by GTZ (2006) is due to:

High Temperature and Long Residence Time: For preventing the by-production of organic pollutant, the complete combustion of input materials is required. It is generally recognized that all organic compounds are adequately destroyed if they are exposed to a temperature of 1,200^{0}C for a residence time of 2s under oxidizing conditions. The conditions in the burning zone of the cement kiln exceed these requirements by a wide margin and thus ensure efficient destruction of even the most stable organic compounds.

High Thermal Capacity: The large amount of heated materials in the cement kiln ensures that the temperature in the kiln is stable without significant oscillations. Thus, in the case of an emergency shutdown due to operational problems, the flow of any organic waste can be halted before the temperature falls below the critical values.

Alkaline Environment: The contents inside the kiln are alkaline. Therefore, virtually all of the chlorines entering the kiln and hydrogen chlorides (HCl) formed during the combustion of chlorinated waste are neutralized by forming into calcium chloride (CaCl2), sodium chloride (NaCl) and potassium chloride (KCl), relatively non–toxic compounds. Thus, emissions of hydrogen chloride from kilns are significantly lower than commercial incinerators. Most of the sulphur oxides (SOx) are similarly trapped as calcium sulphate (CaSO4).

Minimum Amount of Waste Generation: The combustion of waste in commercial incinerators generates ash which needs to be disposed. In contrast, there is no ash equivalent in the cement production process. Any incombustible materials such as metal in the waste become incorporation of cement clinker that eliminates disposal problems.

2.5. Parameters to consider in decision of solid waste fuel substitution

In order to validate a waste fuel's potential, the following operational, emission, product quality factors or variables should be considered (Mokrzycki et al., 2003): Physical state of fuel (solid, liquid, gaseous), Content of circulating elements (Na, K, Cl, S), Toxicity (organic compounds, heavy metals), Composition and ash content, Volatile content, Calorific, or heating value, Physical properties (particle size, density, homogeneity), and Moisture Content.

Although minimum requirements for a waste fuel differ among cement facilities, an example of criteria used by the Lafarge Cement Polska group is shown below (Mokrzycki et al., 2003):

- Heating Value > 6019 BTU/lb (weekly average)
- Chlorine content < 0.2% and Sulfur content < 2.5%
- Heavy metals content < 2500 ppm, out of which: Hg < 10ppm; Cd + Tl + Hg < 100ppm

2.6. Requirement for solid waste fuel substitution

Effective regulatory and institutional frameworks are critical to ensure that cement industry co-processing practices do not have negative health or environmental impacts. If co-processing is conducted in an environmentally sound manner, with proper sorting and pretreatment of waste, acceptance criteria clearly defined, quality control of waste inputs, clear regulations and enforcement to prevent pollution, and rigorous systems for site selection and permitting, co-processing can be an attractive alternative to deal with these waste, using them as alternative fuel and raw material for the cement industry. However, when adequate regulations are not in place, bad practices could lead to negative human and environmental health impacts (Ali *et al,*2012).

2.6.1. Environmental requirement

The high temperatures in rotary kilns ensure that organic substances in wastes are almost entirely converted to CO2 and water and that the emissions concentrations of organic compounds, such as dioxins and furans, are very low. Nonetheless, air emissions, water discharges, and residues from co-processing plants must be carefully regulated, monitored, and reported (Ali *et al,*2012). GTZ (2006) identified three general principles that should be followed to ensure sound environmental performance:

- Use of waste as fuel and material substitution shall not cause negative impact on air emissions and air quality. Therefore, cement production lines shall be equipped with dust and air emission control technology
- Emissions must be monitored in order to demonstrate compliance with the national regulations or corporate rules.
- Pre-processing of waste is required for certain waste streams, particularly due to the fact that for optimum operation, kilns require very uniform raw material and fuel flows in terms of quality and quantity.

2.6.2. Product quality requirement

Product quality requirements are intended to ensure that the use of waste-derived fuels in the cement industry does not result in a negative impact on health or the environment or degrade the cement or clinker's material composition or the technical properties that are essential to its function as a building material (Ali *et al*,2012). GTZ (2006) identified four general principles that should be followed in developing regulations governing the quality of cement products:

- The product (clinker, cement, concrete) must not be abused as a sink for heavy metals.
- The product should not have any negative impact on the environment.
- The quality of cement shall allow end-of-life recovery.

To avoid negative product quality impacts, the quality and type of waste input to kilns should be carefully controlled, and the heavy metal content in the waste inputs should be limited (Ali *et al*,2012). Co-processing plants should set up quality control systems to ensure environmentally safe operation (GTZ, 2006).

2.6.3. Operational requirement

Safe and responsible use of SWM requires careful selection of the feed points in the kiln system as well as comprehensive operational control according to the specific characteristics and volumes of the SWM (GTZ, 2006).

As GTZ (2006) point out, alternative fuels are always fed into the high-temperature combustion zones of the kiln system as shown in figure 5. The physical and chemical natures of the fuel determine the exact feed point, i.e. either the main burner, the precalciner burner, the secondary firing at the preheater, or the mid-kiln (for long dry and wet kilns). Alternative fuels containing stable toxic components should be fed to the main burner to ensure complete combustion due to the high temperature and the long retention time. Alternative materials can feed in the same way as raw material. Volatilized material containing alternative raw materials at low temperatures (for example, hydrocarbons) have to be fed into the high temperature zones of the kiln system.

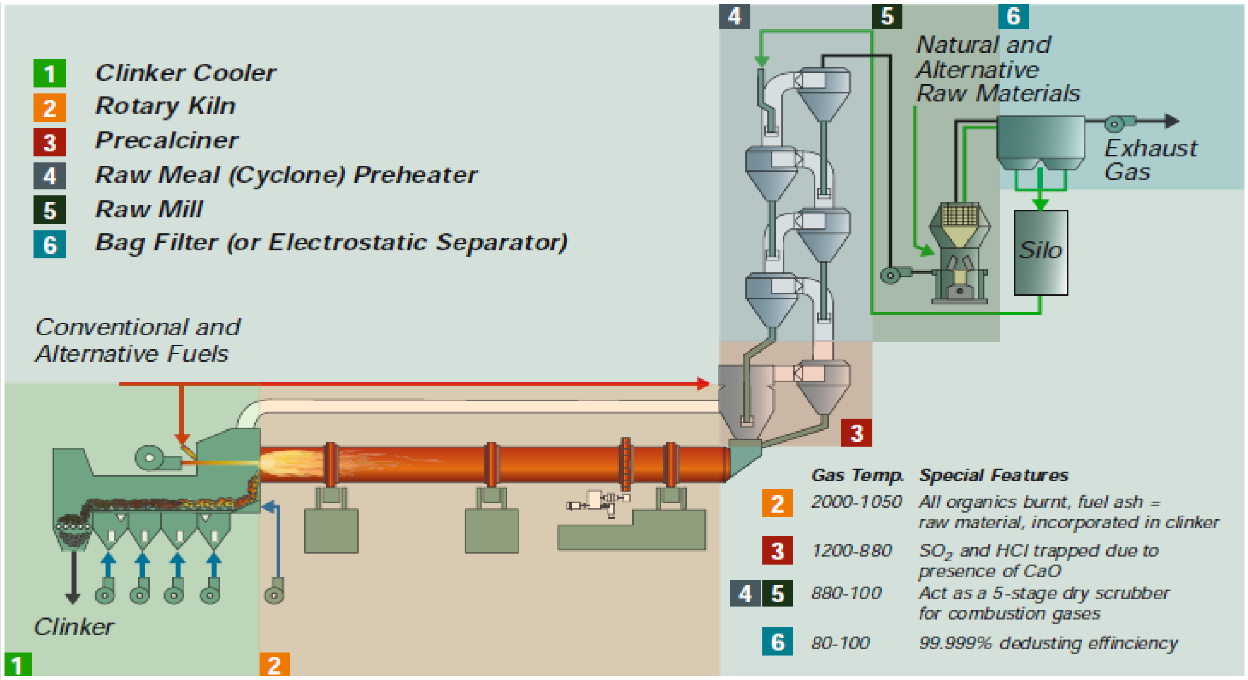


Figure 5: Clinker process and alternative fuel feed point (GTZ, 2006)

The EU WID requires that co-processing plants keep the co-processing gases “at a temperature of at least 850 °C for at least two seconds.” The waste heat from the co-processing process must also be utilized “as far as possible.” The burning process should be monitored continuously by process control technology (Ali *et al*,2012).

Some wastes should never be co-processed; these range from unsorted municipal garbage and certain hospital wastes to explosives and radioactive waste. Other wastes require pre-processing (e.g., drying, shredding, blending, grinding, or homogenization) before they can be used (GTZ, 2006)

2.6.4. Waste quality requirement

The extent of waste processing will depend on the type of material being processed and the requirements of the end user; although operations like mixing and homogenization can improve feeding and combustion behavior, it can involve risks and should be carried out according to a prescribed preparation (WBCSD, 2014). To this end, the following basic principles for pre-processing should be adhered to:

- The chemical quality of the fuel has to meet regulatory standards to ensure environmental protection.
- The calorific quality of the fuel must be stable enough to allow a controlled supply of energy to the kiln to produce homogeneous clinker.
- The physical form of the fuel has to permit easy handling for transportation and controlled flow into the kiln.
- The fuels must not introduce any chemical compounds into the clinker that might be deleterious to the stability of the production process or the performance of the product.

2.6.5. Accepted waste fuel for co-processing

Waste fuels are divided into three distinct categories: solid, liquid, and gaseous waste fuels (Mokrzycki et al., 2003). Examples of each type of waste fuel commonly used are shown in table 2. Each category requires specific plant modifications in order to condition, dose, and fire the alternative fuel. Replacement levels for alternative fuels vary according to physical and chemical properties and are governed differently from country to country.

Table 2: Typical waste fired in cement kilns

Solid waste	Liquid waste	Gaseous waste
• Farming residues (rice husk, peanut husk, etc.) • Municipal waste • Plastic shavings, rubber shavings and used tires • Residual sludge from pulp and paper production • Sawdust and woodchips • Sewage treatment plant sludge • Tannery waste • Tars and bitumen	• Cleansing solvents • Paint sludges • Solvent contaminated waters • “Slope”– residual washing liquid from oil and oil products storage tanks • Used cutting and machining oils • Waste solvents from chemical industry	• Landfill gas

2.6.6. Restricted waste for co-processing

Although conventional fuels may be substituted in part by waste of suitable composition, the quality of the clinker and cement products must be maintained and the products must not be misused as a sink for heavy metals. Waste, which owing to its chemical composition, material properties or potential hazards, may influence the safety or operation of a cement plant, or whose use in a cement plant would lead to significant additional environmental impact, should not be co-processed in cement plants. It is therefore necessary to specify quality requirements for the waste employed and in certain cases to restrict the use of certain wastes.

The 2010 Basel Convention and WBCSD (2014) shows the following waste as normally not recommended for cement kilns: radioactive waste from the nuclear industry; electrical and electronic waste (e-waste); whole batteries; corrosive waste, including mineral acids; explosives and ammunition; waste containing asbestos; biological medical waste; chemical or biological weapons destined for destruction; waste of unknown or unpredictable composition, including unsorted municipal waste; waste raw materials with little or no mineral value for the clinker (i.e. heavy metal processing residues).

Generally, only waste of known composition and known energy and/or mineral value is suitable for co-processing in cement kilns. Moreover, plant-specific health and safety concerns need to be addressed as well as due consideration, which is given to the waste management hierarchy (as a general principle).

2.6.7. Complying with waste hierarchy principle

Municipal waste is a heterogeneous material and consists in developing countries mainly of a native organic (kitchen refuse, green cut), an inert (sand, ash) and a post-consumer (packing material, electronic goods) fraction. Valuable recycling material such as cardboard, hard plastic, glass or metal are often sorted out by the informal (rag pickers) or formal (cooperatives) sector. In some cases, the organic fraction is used for biogas production (anaerobic digestion) or for composting. What is valid for industrial waste holds also true for municipal waste: only sorted waste with a known composition and defined calorific value is suitable for processing as solid waste substitution. The selection has to be based on the waste hierarchy and the social impacts of waste recycling as income generation for the urban poor. Whenever possible the informal sector should be incorporated in collection and sorting activities.

3. MATERIALS AND METHODS

GIZ (2017) and HGST (2006) expressed that the prospect of SWM utilization as an alternative fuel depends on characteristics and availability of SWM, and type of cement industry. Any study with regard to the use of SWM as an alternative fuel for cement facility should carefully examine availability and characteristics of the SWM and operational aspect of the plant. Thus, this study deals with each one of them in the same way as set by GIZ.

3.1. Overview of the study area

The study was carried out in Dire Dawa City Administration (DDCA), which is located in Dire Dawa Administration (DDA), Eastern Ethiopia (see figure 6). Geographically, DDCA is positioned between 09^{o} 28.1” to 09^{0} 49.1” N Latitude and 41^{0} 38.1” to 42^{0} 19.1” E Longitude.

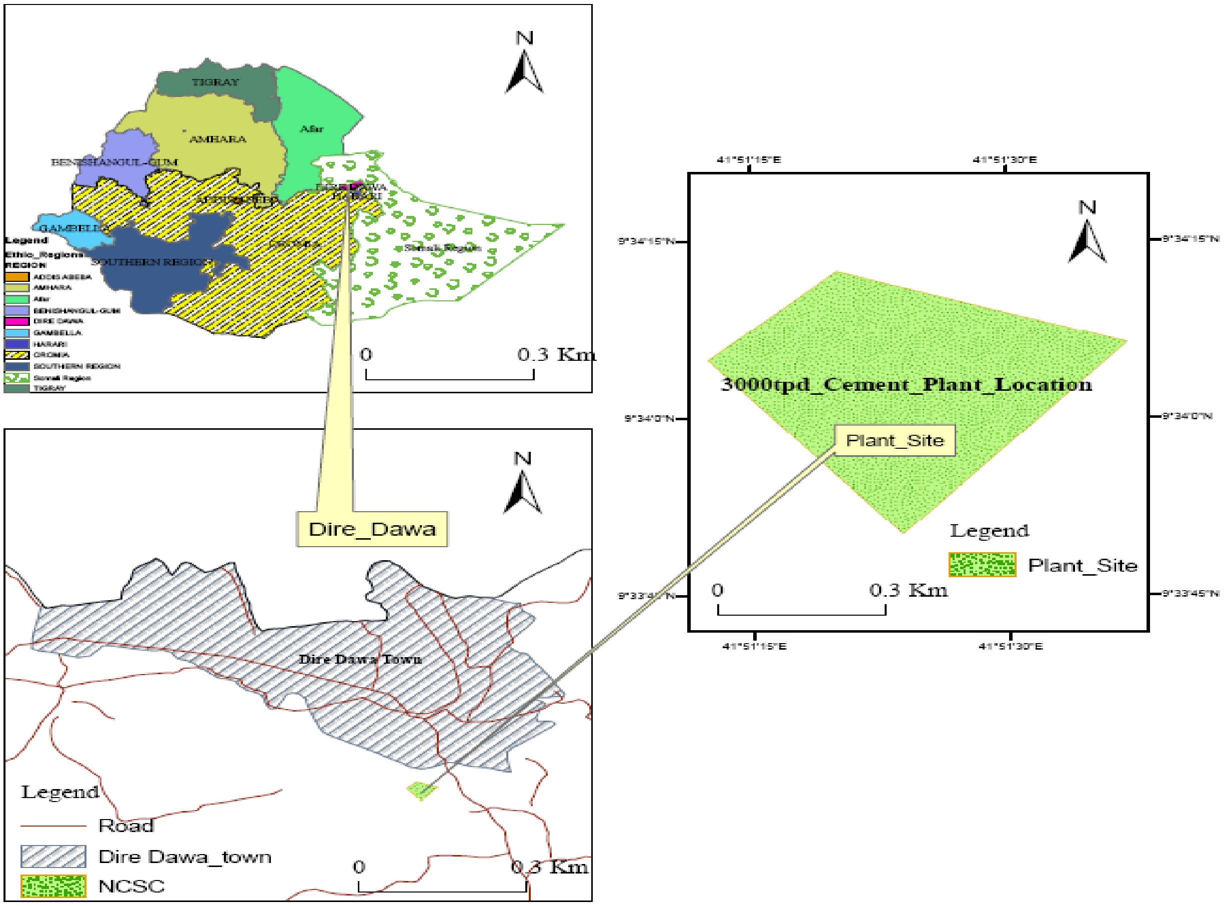


Figure 6:Location Dire Dawa City Administration and NCSCs cement plant

The study area (DDCA) is characterized by urban settlement with territorial land of 2,930ha. According to Land Development and Management Bureau of DDCA (2012), the land use of the DDCA is largely dominated by residential unit (32%) summarized in Table 3-1. On the other hand, the areas occupied by commercial, service and manufacturing industry account for 14%, 10% and 6% respectively. The remaining 40% account for road, green area and river. As shown in table 3, the administrative setup of Dire Dawa consists of nine urban kebele administrations namely: Melka Jebdu (01), Sabian (02), Kezira (03), GendeKore (04), Addis Ketema (05), Megala (06), Legehare (07), Afetesa (08) and Police Meret (09) and 25 rural kebeles. there is variability among Kebeles, most importantly in land use & area.

Table 3: Settlement characteristics of DDCA's kebeles:

Land use & area	Kebele 01	Kebele 02	Kebele 03	Kebele 04&5	Kebele 06&8	Kebele 07&09	Dire Dawa
Total land acres	110ha	820ha	575ha	287ha	172ha	965ha	2,929ha
Residential area	45%	22%	27%	28%	31%	39%	895ha
Commercial area	0%	8%	8%	7%	20%	24%	398ha
Service area	5%	6%	24%	15%	4%	4%	281ha
Manufacturing area	0%	7%	5%	19%	6%	3%	180ha
Other area	50%	57%	36%	31%	40%	30%	1177ha

Source: Local Development Planning Study of DDCA, 2012

DDCA is the second most popups city in Ethiopia next to Addis Ababa. According to the 2007 Population and Household Census growth rate projection, the current population of DDA is estimated 465,600 (including rural kebeles). When disaggregated by place of settlement, the urban population of DDA (DDCA) is projected 294,490 (63%) with average family size of 4.3 (CSA, 2015). The number of population and households found on each Kebele Administration Zone of DDCA is summarized in table 4 below.

Table 4: Population and housing of DDCA's kebeles

Population and land use & area	Kebele 01	Kebele 02	Kebele 03	Kebele 04&5	Kebele 06&8	Kebele 07&09	Dire Dawa
Population	15,440	56,388	25,810	50,617	59,616	86,618	294,489
HH size	3,088	14,097	5,491	15,338	11,923	15,468	65,405

Source: CSA (2015)

The economy of the DDCA is determined by service and industry business activities. Their share in the economy is estimated about 56% and 35% respectively (BoFED, 2016). Over 36% of the population (105,000) livelihood also relied on these economic sectors (CSA, 2014). According to Urban Employment-Unemployment Survey Report (CSA, 2011) wholesale & retail business constituted the largest share (21%) of employment in DDCA, more summarized in table 5. As shown in table 5, there are over 26,259 business activity officially registered by TIO and currently running in 9 Kebele Administration Zone of DDCA.

Table 5: No of business firm and employment in DDCA

Business Category	Percentage of Employee by business type	Number of Employee by business type	Number of Licensed Business	Ethiopian Code of Business licensing category
Health Business (HB)	2.63%	2758.03	127	93
Education Business (EB)	4.84%	5081.17	210	92
Hotel & Restaurant Business (HRB)	10%	10610.97	463	64
Transport, Utility & Maintenance Business (TUMB)	9%	9964.89	1467	41, 63 & 71-75
Public and Privet Office (PPO)	17.65%	18530.15	725	91, 94-99 & 81-89
Wholesales & Retailer Business	23%	23762.53	10675	61
Agricultural Product Exporter & Importer Business (APEIB)	10%	10740.94	1144	65-66 & 11
Manufacturing Industry Business	12.88%	13527.71	248	31-39 & 42-43
Construction Business (CB)	9.55%	10023.62	200	50
Informal Sectors	-	-	11000	-
Total	100.00%	105000.00	26259	

Source: CCA (2011) Electronic Data Base of DDA’s Trade Registration & Foreign Trade Authority, BoFED (2015)

Among the large scale manufacturing industries operating in DDCA, cement industry plays a key role in generating direct and indirect employment opportunity for Dire Dawa’s economy. However, it is also the leading consumer and producer in term of energy and GHG respectively. It is also the only factory which is merely suitable for solid waste material and energy recovery. DDCA has four cement factory with daily production capacity of 4000-ton clinker. When this is supposed to be a good opportunity for SWM substitution, neither the cement factories nor the municipality did an attempt yet.

3.2. Sample design and sample size

Quantitative based descriptive study was carried out to determine the quantity and characteristics of the municipal solid waste generated from DDCA, and accordingly to investigate the potential for energy recovery. The study was made based on sample survey from two Kebele administration while measuring at point of waste generation by using structured questioner and observation.

The samples for waste quantification and characterization study may be taken either directly from generators or at point of waste stream. The samples may also be collected from waste collection vehicles or at a disposal facility. The decision in this regard depends on the trade-off between efforts and the requirements for data. If the data has to be very accurate with respect to waste generators, then samples should be collected at the primary stage of waste generation point/stream (UNEP,2009).

The sampling point for this study accordingly decided based on primary stage of waste generation point/streams. Accordingly, it was stratified into household waste (where the waste originated from residential units) and non-household waste (where the waste originated from institution, manufacturing, commercial and service firms). Accordingly, the target population was set including all household (residential unit) and non-household units (institution, manufacturing, commercial and service firms), who is found in DDCA, respectively. These are supposed to be the leading producer (generators) of municipal solid-waste in DDCA.

The data collected from CSA, BoFED and TIO of DDCA confirmed that there are 294,490 urban dwellers in 65,405 household units and 105,000 employees in about 26,260 non-household units distributed in 9 Administrative Kebeles of DDCA. A sampling frame consisting of the 9 Administrative Kebeles of DDCA was considered for sampling. But, the targeted sampling units was drawn only from 2 Kebeles of DDCA, which are Kebele 02 and Kebele 03 (named “Sabian” and “Kezira” respectively). These Kebeles were chosen upon their representativeness of the population. Table 6 summarized more about the residential and business unit registered in the selected Kebeles.

Table 6: Residential and business unit registered in DDCA

Residential and Business Unit	Kebele 02	Kebele 03	Total
Residential unit	14097	5491	19588
Health Business (HB)	8	6	14
Education Business (EB)	15	26	41
Hotel & Restaurant Business (HRB)	74	166	240
Transport, Utility & Maintenance Business (TUMB)	414	205	619
Public and Privet Office (PPO)	169	112	281
Wholesales & Retailer Business (WSRB)	2643	1134	3777
Agricultural Product Exporter & Importer Business (APEIB)	120	14	134
Manufacturing Industry Business (MIB)	44	30	74
Construction Business (CB)	71	145	216

Source: Electronic Data Base of DDA's Trade Registration & Foreign Trade Authority, BoFED (2015)

It is reported by CCG (2003) that the sample size for waste quantification and characterization study should be determine both on the numbers of waste samples as well as the amount of material. The sample size recommended by different research work and organizational guideline is quite similar. For instance: for household sampling at point of waste generation, 60-80 sample size and/or over 125 pound of waste with 80-90% CV has been recommended by CCG (2003). The same author also recommends 40-60 and 150 pound for non-household waste. Quite similarly, IEPA (1996) also advised in a range of 50-250 samples and 1000-5000kg for both household and non-household unit where sampling devised at point of generation. There was also different statistical procedure to calculate the number of sample at each confidence level. But for higher precision, the sample size was determined upon the requirement of CCG and IEAP. Due to the fact that over 180 sample size were decided considering replication (7 days). It was assumed that the replication would help to reduce the conflict between the number of sample size required for quantification and the amount of waste (in terms of weights) required for characterization study.

Hence, as shown in table 7. from 19588 legally registered residential houses (household units) in two kebeles, a sample size of 90 were selected by stratified random sampling based on socioeconomic status considering income and/or housing conditions. The criteria to establish the status of the residential unit were based on income, roofing and wall materials as shown in table 7. Based on this the samples were taken systematically form 30 high income household; 30 middle income household and 30 low income household. The table below summarizes the information related to socio-economic selection criteria with regard to the number of households that is selected from each socio-economic condition.

Table 7: Sample size and selection criteria for household unit

Income class	Sample size	Selection criteria
Low income	30	Housing material: mud bricks or stone with mud walling and iron sheet roofing
Middle income	30	Housing material: HB walling and iron sheet roofing
High income	30	Housing material: concrete, brick and HB walling/flooring and iron sheet or PBC roofing

With regard to non-household, a sample size of 90 Non-household units were decided to be selected by stratified sampling technique from 5400 legally registered non-household units placed in two kebeles. They were stratified in 10 different business categories, see table 8. Proportional sampling was applied to determine the sample size of each category (strata). These categories were defined based on the nature waste production rate and composition. The strata (business category) were organized according to Ethiopian Standard Industrial Classification (MoT, 2003), summarized in table 5. Sampling point from each category was selected systematically.

Table 8: Non-household sample size and business category

Business Unit Category	sample size
Health Business (HB)	2
Education Business (EB)	4
Hotel & Restaurant Business (HRB)	9
Transport, Utility & Maintenance Business (TUMB)	9
Public and Privet Office (PPO)	16
Wholesales & Retailer Business (WSRB)	20
Agricultural Product Exporter & Importer Business (APEIB)	9
Manufacturing Industry Business (MIB)	12
Construction Business (CB)	9
Total sample	90

3.3. Data collection methods and technique

As any other survey, primary and secondary data were collected to generate descriptive quantitative information on solid waste behavior i.e. the quantity, components and composition of solid waste. Beside to this, further information on operational aspect of the cement facility was collected to satisfy key input parameters of economic and energy modeling operation. Households and institutions were of course the main source of data in the survey. As discussed below, two types of primary data were collected both by means of systematic observation and structured questioner measurement techniques.

3.3.1. Questionnaire

Three distinct questionnaire were organized in order to understand the socioeconomic status of the household unit, business condition of non-household units, and operational restriction and product specification of the NCSC's cement plant. These questionnaires were designed in order to be administrated by personal interview.

As indicated in annex-1, the first questionnaire (household questionnaire) was mainly designed to measure housing condition, family size and income or expenditure information. Whereas, the second questioner: commercial questioner was focused on employee & service type, see annex-3. The purpose of both questionnaire was to measure and control the effect of extraneous variables that may affect the validity and reliability of the observation and finding. These questioners were administrated in accordance of the MoUDC (2012) and UNEP (2009). Prior to measuring, the questioners were circulated for stakeholder's comment and pre-testing and then translated to local language. The questioners were distributed to data collectors followed by providing theoretical training and practical exercise. Accordingly, four individual with level-4 educational background were employed for interview work.

The third questioners (see annex 2) were designed to collect the most important aspects of operational and technology specific actual data of the NCSC's cement plant. The purpose of this questioner was to set up the input parameters of modeling work. Therefore, self-administrated questioner was prepared to be interviewed by the researcher.

3.3.2. Observation

Two different types of observation procedure were adopted in order to generate reliable data for each components of the study objective. Each observation was intrinsically interlinked to one another. Standard measurement tools and visual technique were applied. As part of waste quantification, calibrated weigh scale with level of precision varied ±0.01kg were used for weight measurement. Whereas, as part of waste characterization, manual sorting (using labor force) were used for measurement of waste composition.

Since there was a well-established solid waste collection system in sampling Kebeles, the existing system was found ideal for the purpose waste behavior observation. Therefore, observation was managed in collaboration of the existing solid waste collector namely “Andenet Solid Waste Collector Association”. The area to be covered by the association luckily includes both sampling Kebeles. The Association have well trained and experienced staff for door to door collection and sorting work. They organized with 1-damptrack having a capacity of 6m3 loading for waste transportation and four waste transfer station for temporary waste storage.

On top of that, different sampling materials were employed during observation, which includes 2-plastic sheet, 180-waste collection sacks, 2-hanging weighting scales, 2-wheelbarrow, 2-mesh and 16-labour forces, 4 supervisors and 1 damp track were used for door to door collection, measurement and sorting. Prior to sample collection and observation, the waste collectors and the supervisors were trained about the objective of the assignment, waste collection and sorting procedure and working safety.

As the timing and season of data collection affect the reliability of measurement technique (UNEP, 2009), observation of the household waste behaviors (i.e. measuring the quantity and composition of waste) was conducted for 7-days (5-weekdays and 2-weekend day) between the date of April 3 - 9, 2018 (household) and from February 12 – March 23, 2018 (non-household).

As shown below, three different but interconnected observation procedures were followed in collection of the primary data that is required for household and non-household solid waste quantification and characterization study.

Solid Waste Quantification: The first stage of the observation aimed on generating data for was quantification study. It was managed by measuring and recording of the solid waste quantity that is generated by household and non-household unit. It was collected from primary point of waste generation or stream. It was begun by consulting the willingness of those respondents who were interviewed by questionnaires earlier. Fortunately, the whole 180 respondents were willing. Once they were briefed about the objective of the study, a sampling sacks labeled with name and house number of them were provided by explaining the waste collection. For the purpose of consistency and accuracy of sample collection, a pair of sampling sack labeled with the same sampling code was prepared to be used for switching during sample collection. Every day in the morning for 5 weeks, over 1218-sample were collected while going through each sample unit (or door to door collection). Of which 630 and 588 samples were collected from household and non-household unit respectively. Every day after sample collection, each household samples and low generator business unit samples were transported to nearby transfer station and disposal site for next sampling activity i.e. waste characterization. But those business unit whose waste is large in quantity were measured on the spots. By using calibrated weighting scale, the weight of each sample were measured and recorded two times (at sampling point and transfer station). Data was recorded by using the data sheets showed in annex 4-7. In 5 week periods, over 84884kg solid waste sample were able to measure both from household (1348kg) and non-household unit(83536kg).

Characterization of Solid Waste: the second stage of observation aimed on generating data for characterization of waste component. The data was generated by using manual sorting into 12 specific type of waste component followed by measuring and recording of the weight of each waste components for each category. It was sorted to observe the proportion of waste composition according to the specific type of waste component such as - food/kitchen waste, paper & cardboard, plastic, bones, textiles, biomass, tire & rubber, leather; metals, glass, fine soil and ash, and other. Since the whole observation procedure are interlinked, sorting was made based on the solid waste samples that is collected from Household and non-household unit. This observation was also conducted for seven-day right after the waste quantitate observation. The result of the observations was recorded according to the data sheet showed in annex 4-7. This procedure was conducted once the waste sacks emptied and spreading out on the plastic sheets. Visual and hand sorting technique was employed to sort out the waste component according to the specific category. Whereas, the weight of each waste components were measured by using calibrated weighting scale.

3.4. Methods of data analysis

Both descriptive statistic and mathematical model was considered for data analysis. The collected data including primary and secondary source data is analyzed based on quantitative data analysis methods most importantly using statistical, economic & material and energy balance model.

3.4.1. Data analysis methods for solid waste quantification study

All waste and socio-economic data collected by systematic observation & structured questionnaire were analyzed to determine the daily waste generation rate of DDCA (waste quantification). Descriptive statistic techniques most importantly mean and standard deviation were employed using statistical package of Microsoft excel program. Only waste quantity data that was collected from household and non-household waste generation points were used for waste quantification analysis. Accordingly, the weight of solid waste data recorded during observation and questionnaire measurement were manipulated for analysis of waste quantification as well as to define the mean per capita and/or per employee waste generation rate, and waste generation per household and/or per business unit. The per capita waste generation value was calculated first by averaging the daily weight of waste for each household, then dividing this by the number of people in each household, and then averaging the daily per capita waste generation figures across the studied households. Likewise, the mean waste generation per employee was calculated first by defining the daily mean of waste generation for each business unit, then dividing this by the number of employee to get the daily waste generation rate per employee, and then by averaging this figures across the studied business units (UNEP, 2009 and Shaukat & Sajjad, 2016).

But, the daily total solid waste generation rate of DDCA was calculated based on scale up factor or extrapolation of the mean per capita and per employee value to total population and employee respectively (UNEP, 2009 and Shaukat & Sajjad, 2016). Whereas, the overall waste generation figure in DDCA was estimated by summing the figure obtained from households and non-household waste generation source. Analysis of the waste quantification information was organized according to waste generation source/origin (household & non-household). The data was summarized either of in tabular or graphical formats.

3.4.2. Data analysis methods for solid waste composition & characterization study

Data collected through manual sorting were used to determine the characteristics of the municipal solid waste in terms of waste component and composition. The data was analyzed based on quantitative data analysis methods while using descriptive statistic techniques of mean and standard deviation. The Statistical Package of Microsoft Excel Program were used for mean and standard deviation computation. The overall composition of solid waste material is grouped by 2 major waste material class (combustible and non-combustible) and 12 specific material class. The weight of combustible waste types, which was recorded during manual sorting activity, were used for analysis of waste characterization in which to estimate the daily waste generation rate of combustible waste components.

Whereas, the chemical and physical property of combustible waste component was analyzed based typical property data for the corresponding combustible waste components. This can be found from literature of previous study. This is normally used for proximate estimation of major inputs parameters for optimization modeling. Analysis of the waste composition and characterization is organized in ways of analyzing the waste composition and property while delivering comprehensive information on major parameters or criteria of solid waste energy substitution in kiln. The data was summarized either of in tabular or graphical formats.

3.4.3. Data analysis methods for operational condition characterization

All the necessary operational and technology specific actual data collected from the reference cement plant were discussed to define the most important input parameters for optimal fuel substitution modeling. The information is presented using simple descriptive analysis without the use of statistical technique. Table and figure were applied to support the discussion.

3.4.4. Data analysis methods for optimization

Both Primary and secondary data collected from NCSC’s 3000tpd Cement Plant and observation of the waste characteristics were integrally applied for analysis and determination of optimal fuel substitution rate. Different criteria are set by different cement producer for solid waste fuel substitution. However, the specific criteria that is considered by this study for solid waste material substitution as a fuel for cement facility is typically determine by thermal energy demand with respect to solid waste fuel characteristics, and economic & operational aspect of NCSC’s cement plant.

Thus, both primary and secondary data collected on solid waste quantity & characteristic, and thermal energy & raw material requirement of pyro-processing (clinker production), cost of fuel and additional technology requirement were computed for setting objective and constraint criteria as well as for determination of optimal fuel mix ratio.

Mathematical model which is linear programing was used for optimization of major criteria considered by this study that assist for optimal solid waste fuel substitution decisions. An approach called simplex algorism was employed for optimization, which are based on algorism provides fixed computational rule that are applied repetitively to the problem (iteration) considering several constraint and restrictions. The mathematical model was solved by MS-excel solver.

The model consists linear problem with objective function, and equality and inequality constraint. The mathematical formulation is present in 4.6.2. The objective of the model is to find an optimal solid waste fuel substitution percentage (rate) using optimization algorithms with minimum production cost of clinker (which is a function of fuel and raw material cost) subject to the operational and product specification constraints. The model captures the relationships that exist between the percentage of raw material and coal displaced, and the amount of solid waste fuel substituted (by mass at different rate of substitution) for minimum unit costs of clinker production. The unit cost of raw material and cola for production of clinker for coal feeding is estimated based the recent data collected from NCSC which may include purchasing and transportation cost. However, the unit cost of SWM is define based on calculating the fixed capital investment costs and operating costs

4. RESULT AND DISCUSSION

In order to determine optimal rate of solid waste fuel substitution in cement industry, the amount of waste, the characteristics of waste and operational characteristics of the cement plant are key parameter to be defined ahead. In this section, except some parameters of solid waste characteristics, all other result was discussed on base of primary data analysis. Whereas, the result of solid waste chemical property and cost of waste pre-processing plant (including construction and operation) were discussed up on secondary data analysis (i.e. typical data adopted from literature). The result of fuel and material substitution rate of the process was discussed by demonstrating the problem, definition and formulation of the model. The following section therefore discussed the result according to their order in the objective.

4.1. Socio-economic and employment status of waste generator categories

This section provides the finding of major variables that would considers for estimation of the waste quantity and composition of major categories of the waste generator (household and non-household).

4.1.1. Socio-economic characteristics of household

The generation and composition of household waste are not homogeneous. It is influenced by Socio-economic parameters of income and family size (IEPA,1996) and family size (CCG, 2003), season of the year (UNEP, 2009) and day of the week (Aguilar-Virgen *etal.*, 2009). Sujauddin et al. (2008) also consider other socio-economic parameters such as family size, employment, level of schooling, duration dwelling and age. However, in this study, except income-group all other socio-economic variables were assumed to be included during the random sampling. Thus estimation of waste quantity was made based on different income category of the household. But, in order to validate the result of this approach, the effect of other variables (family size) was attempted to present while comparing with the other research finding.

Out of the 90 households surveyed by this study, all household who are interviewed were found eligible for the socioeconomic analysis as well as for prediction of waste quantity and composition. Total number population in household survey was found about 340 persons. As shown in table 9, the survey result indicates that the mean household size for all income groups was 4.12 persons. The household size per sample unit was relatively smaller than the mean household size of 4.3

estimated by CSA (2015). More numbers of persons per household was observed in high-income groups with mean household size of 6.27 persons.

Table 9:Family size characteristics of the respondent

Income category	Total population	Mean HH size	SD
Low income	95	3.17	2.26
Middle income	88	2.93	1.11
High income	188	6.27	2.32
Total Sample unit	371	4.12	2.48

As summarized in table 10, out of the overall surveyed household, over 13% and 87% of the household was characterized by single family and multifamily respectively. Likewise, most of the high-income household groups was also found multifamily, of which 53% of them was living in family size of 6 and above. On contrary, more than 50% of the low-income group household was found either of single family or couple, see table 10 below.

Table 10:Distribution of family size in sample unit

Family size	Low income category		Middle income category		High income category		Total	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Single family	9	30%	3	10%	0	0%	12	13%
2	6	20%	8	27%	0	0%	14	16%
3 up to 5	9	30%	19	63%	14	47%	42	47%
6 up to 8	6	20%	0	0%	12	40%	18	20%
9 and above	0	0%	0	0%	4	13%	4	4%
Total	30	100%	30	100%	30	100%	90	100%

4.1.2. Number of employee in non-household category

There are several factors that could affect the generation and composition of non-household solid waste. Some of the major one reported by IEPA (1996) and UNEP (2009) entails considering the type of business activity, the processing & production technology, the size of production, the number of employee and waste management policy. In this study, considerable care was taken by grouping based on business type. However, other factors were assumed to be included during the random sampling. The unit for measuring the size of a waste generator would ideally be the number of tons of waste that each generator produces daily or annually, but different variable can serve as a proxy for waste generation such as number of employees, number of students, or number of acres (CCG, 2003). For service and industrial sectors, typically, estimates of generation are correlated with variable that describes the generator, such as number of employees, number of acres, etc. This correlation permits estimates of waste quantities to be “scaled up” to a level larger than the individual generator (UNEP, 2009). Therefore, in this study, the number of employee was considered as proxy variable for non-household waste generation estimation.

Of the total samples, all were found eligible for analysis of non-household category as well as for estimation of the waste quantity. As shown in table 3, the survey result indicates that the mean employee and acre per sample unit for all business category was found over 222 employees and 4.27ha acres respectively. Hence, over 12800-employess and 30.35ha-acres was recorded from all sampling units. More numbers of employees and acres was observed in MIB & EB categories. On contrary, a small number of worker and acres was found in WSRB and TUMB category, summarized in table 11 below.

Table 11: No of employee and acres of the respondent

Category	No of employee		Acres in m2	
	Total	Mean	Total	Mean
Health Business (HB)	487	244	32000.00	16000.00
Education Business (EB)	4206	1052	465000.00	116250.00
Hotel & Restaurant Business (HRB)	243	27	17902.00	1989.11
Transport, Utility & Maintenance Business (TUMB)	177	20	1305095.00	145010.56
Public and Privet Office (PPO)	1119	70	26010.00	1625.63
Wholesales & Retailer Business (WSRB)	71	4	1550.50	77.53
Agricultural Product Exporter & Importer Business (APEIB)	1013	113	115750.00	12861.11
Manufacturing Industry Business (MIB)	5024	419	1016000.00	84666.67
Construction Business (CB)	460	51	55600.00	6177.78
Total	12800	222	3034907.5	42740

4.2. Solid waste quantification

This section provides the total waste quantity estimates for each category of waste generators and the overall figure of the city. Any solid waste materials recovered and removed from the waste stream through waste recycling and recovering technology were not deducted from the total quantity estimates.

4.2.1. Household solid waste quantification

The household waste generation rate in DDCA over the survey period are summarized in table 12 below. The daily per capita waste generation rate was best estimated at 0.43kg/person/dy. The range between the minimum and maximum value was found 1.85kg/person/day. Whereas, based on statistical method of interval estimation, the true per capita waste generation was estimated between 0.35-0.51kg/person/day within 95% confidence level. Hence the overall household waste generation of the city once extrapolating to total population (294,490) was estimated around 126.63 t/day (see table 12).

Comparison of the result obtained by this study with that of MS Consult (2005) finding (0.3kg/person/day) in the same area has shown significant difference with 95% confidence. The reason for this is probably due to the fact that waste generation rate influenced by economic growth of the city (World Bank, 2012). Even though the result of this study differs from earlier study of MS Consult (2005), it is consistent of the recent report of 0.49kg/person/day (Hailu, 2013). On the other hand, no substantial difference was also observed compared to Addis Ababa's figure of 0.5 kg/capita/day (Hayal *et al.*, 2014). The result is also in good agreement with World Bank (2012) specification of 0.09-3 kg/person/day for Sub-Saharan Africa countries.

Table 12:Per capita solid waste generation from households of DDCA (kg/person/day)

Income Category	Mean	SE	SD	Range	Minimum	Maximum	Sum	CI
DDCA's HHWG	0.43	0.04	0.37	1.85	0.01	1.86	38.86	±0.08
Low Income	0.49	0.10	0.53	1.85	0.01	1.86	14.66	±0.20
Middle Income	0.35	0.05	0.29	1.21	0.04	1.25	10.44	±0.11
High Income	0.46	0.04	0.22	1.12	0.21	1.33	13.76	±0.08

Confidence interval calculated at the 95% confidence level

On the other hand, comparison of waste generation rate and income difference is of interest because of its strong correlation. But, the result emerged was barely in contradiction with the results reported in several literatures (world bank, 2012 and UNEP, 2003). As shown in table-12, the mean per capita solid waste generation rate for low income group appeared to be over predicated. No signs of lower waste generation rate from low income group were found than the middle and high income category. This apparent lack of correlation can be justified by the presence of high percentage of ash in waste composition, which has been leading to over prediction of the low income figure.

This result rather varied if unit of measurement (variable) was based on household waste generation rate instead of per capita generation rate. These results thus need to be interpreted with caution. Given that the result revealed that the high income household (3.30 kg/hh) has generated more than the middle income (1.75kg/hh) and low income (1.51kg/hh) groups, see table 13. The variations among the income groups observed by this study was hardly distinguishable from the finding of Hailu (2013), Getaneh Gebre (2015), Dereje (2017) and Beneberu (2011). On the other hand, the rate of waste generation for single family was also higher than other multifamily groups, see table 13 below. Similar finding regarding to waste generation variation between single family and multi-family was also reported by Ojeda-Benitez et al. (2008) and Qu, Li et al. (2009).

Table 13: Household waste generation rate in kg/day

	Low income category			Middle income category			High income category		
Family size	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
single family	1.16	0.20	(0.79-1.41)	1.08	0.29	(0.66-1.46)	0.00	0.00	0.00
2 family	1.76	0.21	(1.52-2.10)	1.72	0.50	(0.89-2.36)	0.00	0.00	0.00
3-5 family	1.75	0.43	(1.12-2.45)	2.46	0.25	(0.2.02-2.76)	1.96	0.42	(1.22-2.39)
6-8 family	1.38	0.28	(1.02-1.67)	0.00	0.00	0.00	3.08	0.57	(2.16-3.56)
9-12 family	0.00	0.00	0.00	0.00	0.00	0.00	4.86	1.10	(3.73-6.83)
Mean	1.51			1.75			3.30		

4.2.2. Non-household waste quantification

As summarized in Table 14, the mean waste generation rate per employee per day for the survey period was calculated at 1.29kg/employee/day. The range between the minimum and maximum value was found 6.69kg/employee/day. Whereas, based on statistical method of interval estimation, the mean waste generation rate per employee in DDCA ranged between 0.98kg/employee/day and 1.61kg/employee/day with 95% confidence level. The total non-household solid waste quantity, which is generated from business unit, once extrapolated to total city's employee (105,000), was estimated over 135.88 t/day.

Table 14: DDCA's non-household waste generation rate (kg/employee/day)

Category	Mean	SE	SD	Range	Minimum	Maximum	Sum
DDCA	1.29	0.16	1.48	6.72	0.03	6.75	116.47
HB	0.80	0.08	0.11	0.16	0.72	0.88	1.60
EB	0.10	0.05	0.11	0.23	0.04	0.27	0.42
HRB	1.16	0.26	0.79	2.53	0.41	2.94	10.44
TUMB	2.09	0.86	2.57	6.50	0.25	6.75	18.79
PPIO	0.21	0.04	0.15	0.58	0.06	0.64	3.42
WSRB	1.25	0.23	1.05	3.39	0.21	3.60	24.94
APEIB	2.42	0.66	1.99	5.88	0.20	6.08	21.82
MIB	1.01	0.36	1.26	3.70	0.03	3.72	12.10
CB	2.55	0.38	1.14	3.05	1.26	4.31	22.93

A comparison of the result obtained from this research with that of Hailu (2013) study highlights large difference in quantity (11.14kg/business/day). This is due to the fact that the difference in methodology employed by Hailu (2013). The scale up factor considered by Hailu (2013) was generator base. Likewise, in contrast to this figure, recent studies carried out by other researcher in various towns of Ethiopia have came up with different figure because of the difference in methodology. The scale up factor they prefer to use was generator based or acres based.

With regard to business category, the large value was recorded in APEIB (2.45kg/e/d), CB(2.55kg/e/d) and TUMB (2.09kg/e/d). The reason for higher record of waste in AGEIB business category as such is related with the nature of business. The AGEIB sample units involve some of the business groups who have been engaged on exporting chat, vegetable & fruit, coffee & grain, and livestock & meat. The process of grading work observed in AGEIB business often discarded a huge quantity low grade product and leftover parts in order to meet the foreign market demand. This was more noticed during waste sorting procedure. It might also associate with the operation of the work depend on manual operation. Whereas, the reason for higher waste generation in TUMB and CB category is linked with the presence of high density product like metal & steel scraps and tyres. The least figure recorded in PPIO and EB reflect the presence of low density waste material like paper and plastic.

4.2.3. Overall solid waste generation rate in DDCA

As shown in table 15 below, the overall waste generation figure of the city while summing up the household and non-household waste quantity was found over 262 tons per day. Out of this, the non-household waste quantity (52%) formed the highest component.

Table 15:Total solid waste generation from DDCA (kg/day)

Source of solid waste	Per capita/ per employee waste quantity per day (kg)	No of people/ employee	Daily waste generation rate (kg)	Percentage contribution
Household waste	0.43	294,490	126630.70	48.32
Non-Household waste	1.29	105,000	135450.00	51.68
Total			262080.70	100

4.3. Solid waste composition

Not all waste materials are suitable for co-processing in the cement industry. When wastes are selected for co-processing, several factors must be considered, one of which however is the waste type including the physical and chemical composition of the wastes. Examples of wastes material that are not suitable for co-processing in the cement industry are waste from nuclear industry, infectious medical waste, entire batteries, metals, glass, and mineral sand. GTZ (2006) gives a full list of solid waste materials suitable for co-processing.

This section presents the composition of solid waste material generated from household and non-household waste stream and the city as a whole. The results presented herein are based on the data obtained from field sample collection and sorting activities performed from February to April, 2018. The waste composition profile presented here in percentage is further computed to estimate or obtain the daily tonnages of each waste materials.

Solid waste is broadly classified into energy recoverable (combustible) and non-recoverable (non-combustible), organic and inorganic, hazardous & non-hazardous, recyclable and non-recyclable, and bio-degradable and non-biodegradable. In this study, waste composition is grouped into energy recoverable and non-recoverable that are suitable for fuel substitution in cement industry. Energy recoverable material that is used for co-processing include food/kitchen waste, paper & cardboard, plastic, bones, textiles, biomass, tire & rubber, and leather; whereas non-recoverable material denoted by metals, glass, fine soil and ash, and other. Traditionally, combustible waste fraction can be divided into six groups, i.e. food residuals, wood, paper, textile, plastic, and rubber wastes (Zhou et al., 2013). All waste materials mentioned herein is further refined in Annex 9.

4.3.1. Household waste composition

A total of 1348.25 kg samples waste was sorted to determine the composition of household waste, out of which 315 kg belonged to the low income category, 446.25 kg to the middle income, and 587 kg to the high Income. The overall composition of solid waste material from household waste stream was grouped by 2 major waste material class and 12 specific material class as presented in Table 16 below.

Table 16 illustrated the result of household waste composition, the largest fraction was represented by kitchen/food waste (29.47%) followed by biomass waste (11.74%), plastic (9.76%), Paper & cardboard (8.60%), bone (4.72%), tire & rubber (4.33%) and textile (4.11%). While the least generated waste component was leather (1.21%), glass (3.56%), metal (3.91%). This reflects that 73.94% of household waste composition are highly potential for energy recovery. In terms of tonnage, of the 126.63 tone of solid waste material generated from household stream in daily base, over 93.63tpd solid waste material has the potential to be used for energy recovery and/or fossil fuel substitution; Table 16 provides the amount of household waste component that can be used for energy recovery in terms of tonnage.

Table 16:DDCA's household waste composition & potential for energy recovery

waste component	Household Solid Waste Streams			DDCA's waste composition	
	Low income	Middle income	High income	Mean	tonnage
Food or Kitchen waste	24.98%	26.94%	33.80%	29.47%	37.32
Biomass waste	8.26%	13.35%	12.38%	11.74%	14.87
Plastic	8.61%	10.24%	10.02%	9.76%	12.36
Paper & cardboard	6.06%	10.21%	8.74%	8.60%	10.89
Bone	3.30%	4.49%	5.65%	4.72%	5.98
Tire & rubber	1.63%	5.70%	4.75%	4.33%	5.48
Textile	3.17%	4.95%	3.99%	4.11%	5.20
Leather	1.52%	1.13%	1.11%	1.21%	1.53
Total energy recoverable waste				73.94%	93.63
Glass	2.20%	3.69%	4.99%	3.91%	4.95
Metal	2.56%	3.96%	3.79%	3.56%	4.51
Fine soil & Ash	34.63%	12.55%	8.08%	15.76%	19.96
Other	3.07%	2.80%	2.72%	2.83%	3.58
Total energy non-recoverable waste				26.06%	33.00

With regard to income category, the largest fraction of energy recoverable materials was generated by high income class at 80.44% followed by middle income (77%) and low income (57.56%). As summarized in table 16 above, food waste, biomass, plastic and Paper/cardboard accounted the highest percentages among energy recoverable wastes components generated from all income category, respectively. Whereas, bones, tire/rubber, textile and leather were relatively of lower in fraction. Middle income household's waste composition most closely resembles that of high income category. On contrary, the low income household rather discard the largest quantity of fine soil and ash waste (34.63%). The presence of large fraction of ash and fine soil might be the reason that the use fuelwood and/or charcoal for cooking by large, and the nature of the physical environment (air quality) in the area characterized by high concentration of fugitive dusty and/or particulate matter. The large fraction of biomass in all income category might be attributed to the presence of chat residue (locally called *Geraba*) and shedding tree's residue. This figure may be further attributed by seasonal factor i.e. since the sampling was conducted in tree shading season. In general, the largest percentage of organic waste composition (food and biomass waste) and the small proportion of inorganic waste (plastic, paper and other) observed by this study is found normal as it agrees with most values reported for third-world towns and cities (WB, 1999).

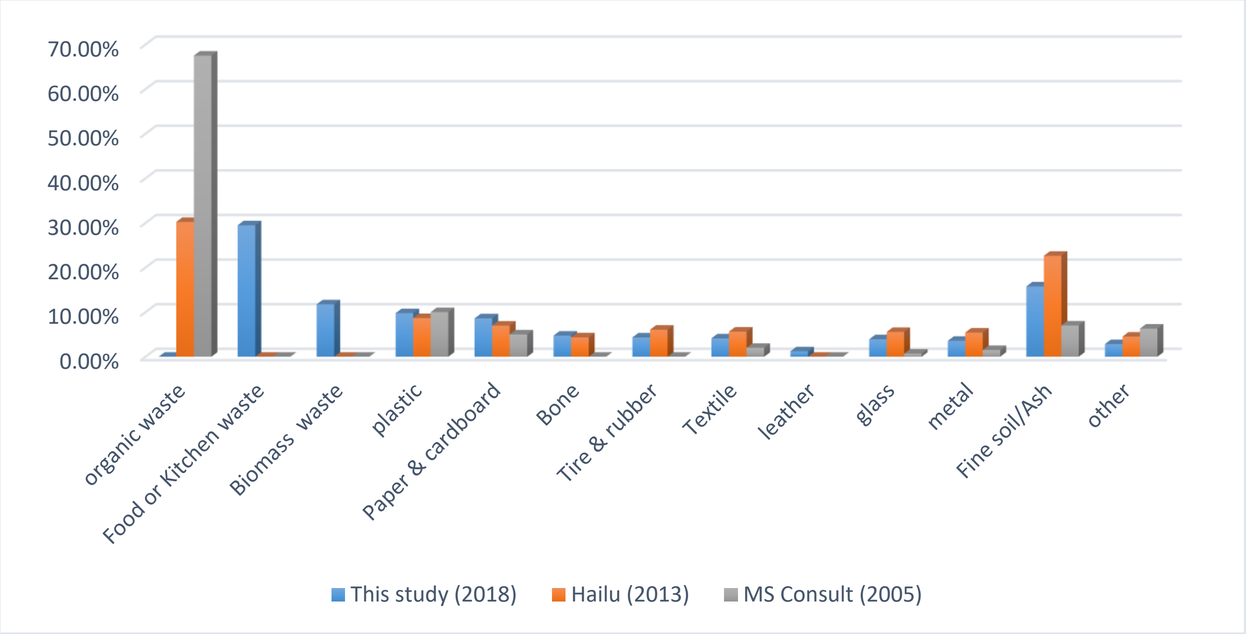


Figure 7:Comparison of household waste composition with previous study

A comparison of household waste composition between the previous surveys of MS Consultancy (2005), Hailu (2013) and this study highlights a modest increase in paper/cardboard, plastic, bone and leather, and a modest fall in tire/rubber and textile. A comparison of the result is shown in Figure 7. A shift towards an increased fraction of plastic and paper in the waste composition that is experienced in the high-income countries could be normal to see either in the middle or low income countries when they are experiencing economic growth and urban development (Jayarama, 2016). On the other hand, there is also a great difference among the profile of two compositions: food waste & biomass. It should be noted that, the huge variation observed in food and biomass waste may be due to the different methodology employed in the waste characterization survey. This means that when this study breakdown the organic waste component into food and biomass waste, the study made by Hailu and MS consult measured differently while combing both waste component into organic waste material. As for the composition of plastic, paper and bone, the increase in percentage might be attributed to the change in lifestyle of the people and/or the replacement of traditional packaging by paper & plastic packaging. It was evidenced by the presence of PET bottles, cardboard and plastic bag packaging, and diapers.

In contrast to this figure, recent studies carried out by other researcher in various towns of Ethiopia have shown quite comparable figure. For instance, in Woldia & Bati Town, the composition waste material for energy recovery accounted for 73% and 72% respectively: in which food & biomass waste accounted for 55% & 61% respectively, paper 8% & 4.5%, plastics 9% & 5.6%, Bone 1% & 0.1%, and textiles 1% & 0.7% (Getaneh Gebre, 2015). On other hand, in Aweday Town, it maked up 62.76% of the household waste components: in which food & biomass waste constituted over 58% followed by paper 1.63%, plastics 4.76%, Bone 0.11%, and textiles 0.58% (Beneberu, 2011). Relatively lower value was reported by FfE (2010) in Bahir Dar with 32% composition.

4.3.2. Non-household solid waste composition

A total of 85.24-ton waste samples was sorted to determine the composition of non-household waste components. The overall composition result was developed by aggregating data from 9 business categories (non-household waste stream points). As shown in Table 17, the composition of waste material was grouped into 12 major material class similar to household waste category.

Overall composition result of non-household waste materials is presented in Table 17. As shown, energy recoverable material accounted for 58.24% of non-household waste stream. Most of these waste was biomass (21.21%), kitchen waste (11.40%), plastic (8.04%), paper & cardboard (7.37%), textile (4.66%) and tire & rubber (4.01%). From Table 17, it can also be noted that over 78.89 ton of solid waste material was highly potential for energy recovery or fossil fuel substitution, which is from the daily tonnage of 135.45 ton of solid waste material generated from non-household waste generator,.

Table 17:DDCA's non-household waste composition & potential for energy recovery

Waste Component	Non-household Solid Waste Streams									DDCA's NHH waste Composition	
	HB	EB	HRB	TUMB	PPIO	WSRB	APEIB	MIB	CB	average	tonnage
Food waste	38.64	9.42	52.81	9.51	20.46	1.01	5.31	12.50	1.59	11.40	15.44
Biomass waste	0.00	0.69	0.92	0.99	4.38	6.36	86.05	6.39	12.15	21.21	28.73
Plastic	4.66	20.09	4.30	30.05	10.70	22.87	3.26	9.53	3.28	8.04	10.89
Paper/cardboard	7.12	27.64	4.27	24.44	45.56	49.20	2.25	7.32	5.13	7.37	9.98
Bone	9.57	4.68	22.50	0.00	0.00	0.25	0.59	1.01	0.24	1.53	2.07
Tire & rubber	0.00	6.29	0.80	28.98	2.87	0.40	0.00	5.01	3.44	4.01	5.43
Textile	0.00	3.14	0.72	0.60	0.15	0.06	0.05	7.50	0.08	4.66	6.31
Leather	0.00	0.00	0.00	0.07	0.00	0.06	0.00	0.03	0.00	0.02	0.03
Total combustible waste										58.24	78.88
Glass	8.24	3.87	1.92	1.51	3.89	5.41	0.00	3.57	0.84	2.71	3.67
Metal	2.48	1.16	1.31	0.54	1.27	1.09	0.00	8.90	10.72	6.75	9.14
Fine soil &Ash	1.44	21.31	6.26	3.08	8.05	7.84	2.49	13.02	41.25	13.59	18.41
Other	27.85	1.71	4.21	0.23	2.68	5.46	0.00	25.22	21.28	18.71	25.34
Total non- combustible waste										41.76	56.56

With regard to business category, the largest fraction of energy recoverable materials was generated by APEIB (97.51%), TUMB (94.64%), HRB (86.32), PPIO (84.12%) and WSRB (80.21%). As summarized in table 17 above, biomass, food waste, Paper/carton, plastic, textile and tire were the highest percentages among energy recoverable wastes, respectively. Whereas, bones and leather were relatively of lower in fraction.

Biomass waste as shown in table 17 was largely produce by APEI and construction business. This reflected the fact that the nature of APEI business discard more leftover part brought together with the product. Whereas, the large composition of biomass in construction business was attributed to the large quantities of broken or worn-out wood and timber product from land clearing, demolishing, scaffolding, woodwork and packaging - wood pallets used for deliveries. The large fraction of food waste including bone though small in quantity were relatively generated from HRB and HB due to the fact that the nature of business. But, a small fraction of food waste was also present in all business category, as most of them has an on-site restaurant or cafeteria. Both plastic and paper waste was recorded more in PPIO, TUMB and WSRB category. The composition of plastic, and papers & cardboard in combined though relatively higher in PPIB and WSRB business category, it was produced in small amount by other business categories as well. The relative high quantity of both waste compositions in PPIO, WSRB & TUMB business category may be due to the fact that the intrinsic nature of the business depends on plastic & paper packaging material and publishing/printing material. A large percentage of tire waste was recorded in TUMB. It is reasonable to assume that the high quantity of tire could be because of the nature of the business. But in small fraction, it was generated by EB, MIB, PPIO and CB as well. The reason for this may be linked to the onsite repair & maintenance service performed by some companies.

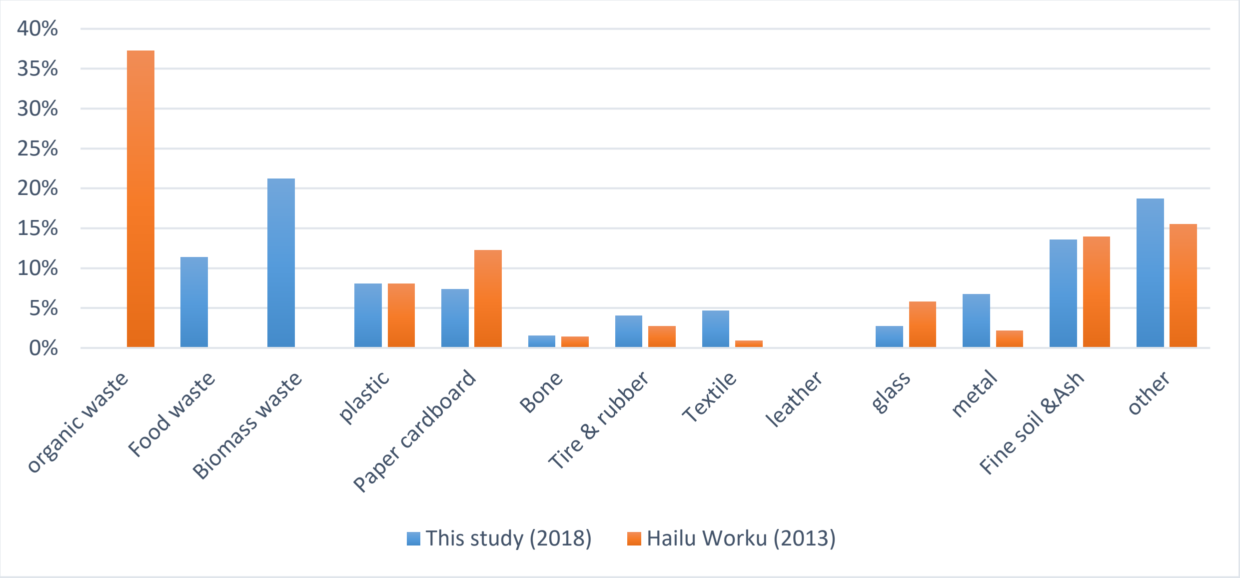


Figure 8: Comparison of non-household waste composition with previous study

A comparison of non-household waste composition between the previous survey of Hailu (2013) and this study highlighted a close similarity in plastic and bone, see figure 8. The close similarities between the two results indicated a consistent profile of non-household waste component. There are a number of modest differences in four waste compositions though. As shown in figure 8, There is a modest drop in paper/cardboard (12.23% compared to 7.37%) and glass (5.82% compared to 2.71%). On contrary, the proportion of tire, textile and metal waste composition has shown a modest increase from 0.89% to 4.66% and from 2.13% to 6.75% respectively. In both case, there can be no conclusive reasoning behind these drop and rise in percentage of waste composition. On the other hand, there was also a clear difference between the profile of two compositions: food waste & biomass. It should be noted that, the huge variation observed in food and biomass waste could be due to disparity of methodology applied for waste characterization. The previous surveys were only measured the waste that goes to landfill, and did not take into account the materials discarded and burned on site and diverted towards recycling or reused.

In contrast to this figure, studies carried out by other researcher in various cities of Ethiopia have shown quite comparable figure. For instance, in Woldia & Bati Town, the composition waste material for energy recovery accounted for 73% and 77% respectively: in which food & biomass waste accounts for 50% & 51%, paper 5% & 9.3%, plastics 6% & 8%, Bone 8% &7.8%, and textiles 3% & 0.6% (Getaneh Gebre, 2015).

4.3.3. Overall solid waste composition of DDCA

Overall waste composition result for the city in general and for business & residential unit in specific are summarized in table 18. The overall composition result for the city was developed based on weighted average method. Which means that the composition results for both waste stream was combined after multiplying for their weighted factor as shown in table 18. The relative tonnages or percentage, which is calculated based on percentage contribution of each waste stream in table 15, served as the weighting factors.

As summarized in table 18, food waste, biomass waste and ash/fine soil were dominant in overall waste composition. The overall waste composition has higher percentage of energy recoverable waste (65.83%) compared to the non-recoverable material (34.17%). In terms of tonnage, this figure indicates that an estimated 172.52 tons of energy recoverable waste material can be extracted from DDCA. Therefore, this tonnage can be effectively used as fuel and material substitution for co-processing.

Compared to the 2013 survey result of Hailu (2013), the figure has changed by 16% (148tones/day compared to 172 tones/day). This indicate that the generation of energy recoverable waste material has been increasing in the DDCA probably due to the increased population, consumption pattern, life style behavior and economic development etc.

Table 18:DDCA's Waste composition and solid waste potential for waste energy recovery

waste component	HH-waste composition			NHH-waste composition			DDCA-waste composition	
	unweighted Average	weighting factor	weighted average	unweighted Average	weighting factor	weighted average	Average	tonnage
Food waste	29.47%	48.32%	14.24%	11.40%	51.68%	5.89%	20.13%	52.76
Biomass waste	11.74%	48.32%	5.67%	21.21%	51.68%	10.96%	16.63%	43.59
Plastic	9.76%	48.32%	4.72%	8.04%	51.68%	4.16%	8.87%	23.25
Paper/cardboard	8.60%	48.32%	4.16%	7.37%	51.68%	3.81%	7.96%	20.87
Bone	4.72%	48.32%	2.28%	4.66%	51.68%	2.41%	4.69%	12.29
Tire & rubber	4.33%	48.32%	2.09%	4.01%	51.68%	2.07%	4.16%	10.91
Textile	4.11%	48.32%	1.99%	1.53%	51.68%	0.79%	2.78%	7.28
Leather	1.21%	48.32%	0.58%	0.02%	51.68%	0.01%	0.60%	1.56
Total combustible waste	73.94%	48.32%	35.73%	58.24%	51.68%	30.10%	65.83%	172.52
Glass	3.91%	48.32%	1.89%	2.71%	51.68%	1.40%	3.29%	8.62
Metal	3.56%	48.32%	1.72%	6.75%	51.68%	3.49%	5.21%	13.65
Fine soil Ash	15.76%	48.32%	7.62%	13.59%	51.68%	7.02%	14.64%	38.36
Other	2.83%	48.32%	1.37%	18.71%	51.68%	9.67%	11.04%	28.93
Total non-combustible waste	26.06%	48.32%	12.59%	41.76%	51.68%	21.58%	34.17%	89.56

4.4. Solid waste characteristics

Physical and chemical parameters of interest for waste characterization depends very much on the purpose of the study. Normally physicochemical analyses may include bulk density, moisture content, size (sieve) analysis, proximate analysis (ash, volatile matter, fixed carbon), specific energy (calorific value) and elemental analysis. This research focused on energy content, and moisture, ash and elements property of the waste fraction, since these are the primary factors in deciding the rate of solid waste fuel substitution in cement kiln. These can be determined based on direct & indirect approach and market based approach (Brunner and Ernst, 1986).

Direct approach, which examines individual samples of waste materials, was employed because of its advantage to investigate specific material fractions within a particular waste stream and offers more flexibility for research as sampling point and waste fraction can be easily adjusted to different research questions. Direct waste analysis can be achieved based on the following five steep process (Götze *et al.*, 2016): i) choosing of the sampling point and fractions to be sorted, ii) collecting the waste sample and performing the sorting procedure, iii) reducing the mass and particles' size of material fractions, and finally iv) analyzing the physicochemical properties. The result of the first three process is already discussed herein before. Because of cost constraint, the physicochemical analysis was not performed. However, in the absence of direct measurement proxy-estimation based on typical property of material from literature is possible to make conservative estimation Sou Hosokai *et al.*, (2016), Meraz *et al.*, (2013); UNEP (2005). So, the following section discuss essential physicochemical parameter of the waste fraction that is relevant for a particular co-processing application.

4.4.1. Elemental composition & MC of the combustible waste component

Determination of elemental, ash and moisture content of solid waste is important parameter for calculating energy content and chemical formula of the solid waste (Sajjad & Shaukat, 2016). These can be determined in laboratory from proximate and ultimate analysis. The other method of finding these contents is using the typical data from literature and previous study (Sajjad & Shaukat, 2016). A typical elemental composition i.e., percent by weight of carbon, hydrogen, oxygen, nitrogen and sulfur content in waste fraction is showed in Annex 11 along with typical properties of moisture and ash.

The use of typical value (see Annex 11) for estimation of moisture and elemental content of solid waste depends on the composition of the wastes (type of waste), the season of the year, and the weather conditions (Sajjad & Shaukat, 2016). Despite this factor, the type of waste and physical property of waste are closely interlinked (Götze *et al.*, 2016).

By using the typical value, the approximate elemental, ash and moisture content of the combustible waste fraction for DDCA was calculated as shown in table 19. From this table, the amount of moisture in combustible waste fraction was estimated about 60%. Whereas the ash and volatile element of the combustible waste fraction, which is supposed to be used for energy and material recovery, was estimated around 40% or 68.77 ton per day. Where carbon and oxygen accounted for the largest fraction of 34%.

Table 19:Approximate elemental, ash and moisture fraction in combustible waste

Waste material	Wet weight (%)	MC (%)	Dry weight (ton)	Ash (ton)	C (ton)	H (ton)	O (ton)	N (ton)	S (ton)
Food waste	52.76	70	36.93	1.8466	17.7274	2.3636	13.8864	0.9602	0.1477
Biomass waste	43.59	64.9	28.29	1.2730	13.5226	1.6974	10.7502	0.9619	0.0849
Plastic	23.25	1.4	0.33	0.0326	0.1953	0.0234	0.0742	0.0000	0.0000
Paper/cardboard	20.87	5.9	1.23	0.0739	0.5356	0.0739	0.5418	0.0037	0.0025
Bone	12.29	8	0.98	0.2819	0.4139	0.0573	0.1524	0.0739	0.0037
Tire & rubber	10.91	0.8	0.09	0.0172	0.0628	0.0053	0.0010	0.0002	0.0009
Textile	7.28	10.5	0.76	0.0191	0.4204	0.0505	0.2385	0.0352	0.0008
Leather	1.56	10	0.16	0.0156	0.0936	0.0125	0.0181	0.0156	0.0006
Total combustibles fraction in ton dry base	172.5	-	68.77	3.56	32.97	4.28	25.66	2.05	0.24
Total Combustibles fraction in % dry base	-	-	100%	5.18%	47.95%	6.22%	37.32%	2.98%	0.35%
Total Combustibles fraction in ton wet base	172.5	103.75	-	3.55	32.97	4.28	25.67	2.05	0.24
Total combustibles fraction in % wet base	100%	60.14%	-	2.06%	19.11%	2.48%	14.88%	1.19%	0.14%

Adopted from Brunner and Schwarz (1983) and Sajjad & Shaukat (2016)

Defining the chemical formula for the combustible fraction of the waste is key factor in determining the oxygen requirement during combustion. Following a five steeps procedure as recommended by Sajjad & Shaukat (2016), the approximate chemical formula for combustible fraction of the waste was calculated as illustrated in Annex 10. The approximate chemical formula of combustible fraction of the solid waste in wet base (as received) was represented by C_{365} H_{2102}

O_{998} N_{19} S, and in dry base by C_{365} H_{570} O_{213} N_{19} S. The calculated chemical formula for dry and wet scenario is consistence with several literatures (Sajjad & Shaukat, 2016; Younes et al., 2013)

4.4.2. Heating value of the combustible waste fraction

Heating value of waste are important parameter in using waste as a fuel. Heating values express the amount of energy released on combustion of a given quantity of fuel. The higher heating value (HHV) includes the heat obtained by condensing the water vapor produced by combustion. The lower heating value (LHV) does not include the water vapor condensed from combustion. Typically, if a process exhausts the water vapor produced by combustion, then the LHV may be used. If the process condenses the water vapor produced by combustion, then the upper heating value may be used. In practice, the heating value of a fuel is measured with bomb calorimetry based on standard methods such as ASTM-D2015. Another method to evaluate the heating value is the use of mathematical equations which are based on the waste component Khan & Abughara (1991), Tchobonoglous & Frank (2002) and Sajjad & Shaukat, (2016) and based on chemical parameters of the waste material in a wet or dry basis Mearz *et al.* (2013) and Sou Hosokai *et al.* (2016). Several kinds of empirical estimation equations have been reported, such as those based on the ultimate analysis (elemental composition), proximate analysis, chemical composition and waste material. Since a fuel produces heat owing to the recombination of chemical bonds between its elements, equation based on the ultimate analysis should be the most preferable method among the proposed empirical estimation methods (Sou Hosokai *et al.*, 2016).

Modified-Dulong formula are widely used and have been proven to be quite precise for different kinds of wastes by several research. In this study. Only HHV of the compostable solid fraction was calculated based on the modified-Dulong formula (Tchobanoglous et al., 1993) as shown in equation (1).

HHV (in dry/wet base) $=(80.5*C)+(338.6*H)-(42.3*O)+(22.2*S)+(5.55*N)$ …… Equation (1)

HHV is expressed on dry or wet base (Kcal/kg). Where C, H, O, S and N represent Carbon, Hydrogen, Oxygen, Sulphur and Nitrogen respectively in % by mass on dry or wet base. The mass fractions of the elements were derived from approximate chemical formula estimated for dry base (C_{365} H_{570} O_{213} N_{19} S) and wet base (C_{365} H_{2102} O_{998} N_{19} S). Table-20 presents the percentage of elemental fraction of combustible solid waste.

Table 20:Percentage of element composition

Element	No of atom per mole		Atomic weight	Weight contribution of element		percentage contribution of element	
	dry base	wet base		dry base	wet base	dry base	wet base
Carbon (%)	365	365	12	4384	4,384.17	50.6%	19.5%
Hydrogen (%)	570	2,102	1	570	2,102.31	6.6%	9.4%
Oxygen (%)	213	980	16	3412	15,673.80	39.4%	69.8%
Nitrogen (%)	19	19	14	273	272.67	3.1%	1.2%
Sulphur (%)	1	1	32	32	32.00	0.4%	0.1%
Heating value						4655 Kcal/kg	1798 Kcal/kg

By using the elemental composition of the combustible waste fraction that is presented in table 20 and equation 1; the high heat value or net calorific value of the combustible fraction of waste component when received (wet weight) and dry base was calculated around 4655Kcal/kg and 1798Kcal/kg respectively. The computed heating value from Equation (1) is in close agreement with the proximate HHV value reported by Khan & Abughara (1991), Tchobonoglous & Frank (2002) and Sajjad & Shaukat (2016)

4.4.3. Chemical Composition of ash residue from combustibles waste fraction

The chemical properties of ash are also an important parameter when deciding material and energy recovery of solid waste in cement plant. When SWM are used as fuel substitution in cement kiln, the ash residue from SWM fuel replaces part of the components of the raw materials, and therefore positively or negatively influence the quality of the product. The chemical composition of the ash residue from SWM is normally determined in laboratory after proximate and ultimate analysis. The procedure begins after burning of the dried sample at temperatures higher than 500 ^{0}C for a defined period of time (Götze et al., 2016). The chemical composition of raw SWM is as well determined after removing (and separately accounting for) the large inert materials (metals, glass, and ceramics), and shredding and performing laboratory analysis on the remaining fraction (Tchobanoglous et al., 1993). In the absence direct laboratory analysis or primary data, adopting typical ultimate analysis value from literature is often applied by several literatures but with high pre-caution as the data from literature significantly influences the reliability of the assessment (Götze *et al.,* 2016; Tchobanoglous *et al.,* 1993). Despite the limitations of typical data use, analysis of chemical composition in this paper was made based on the typical value presented by GBB (1990), cited by Tchobanoglous et al. (1993). Table 21 column 2 shows a typical ultimate analysis and analysis of non-combustibles for major and trace metals.

Table 21:Chemical composition of the inherent ash residue from combustibles waste fraction

Ash Chemical composition	Typical ash Composition in %	% of ash in SWM (dry base)	% of ash in SWM (wet base)	SWM Chemical composition (dry base)	SWM Chemical composition (wet base)
SiO2	5.00	5.18%	2.06%	0.26	0.11
Al2O3	33.21	5.18%	2.06%	1.72	0.68
Fe2O3	0.00	5.18%	2.06%	-	0
CaO	30.20	5.18%	2.06%	1.56	0.62
MgO	0.00	5.18%	2.06%	-	0
K2O	13.12	5.18%	2.06%	0.68	0.27
Na2O	17.50	5.18%	2.06%	0.91	0.36
SO3	0.00	5.18%	2.06%	-	0
Cl	0.00	5.18%	2.06%	-	0
Other TM (Cr, Pb, Cd, Cu, Ni, Zn, Sn)	0.97	5.18%	2.06%	0.05	0.02
Total	100.00	5.18%	2.06%	5.18	2.06

Source: adopted from GBB (1990) as cited by Tchobanoglous et al. (1993)

The daily tonnage of inherent ash from combustible fraction as illustrated in table 19 is over 3.5tpd. In terms percentage, this figure is calculated on base of dry base and wet base (i.e. with and without water), which is respectively 5.18% and 2.06%. Hence, the amount of trace metals fraction in combustibles waste component was estimated over 0.05% and 0.02% respectively for dry and wet base (see table 21). Trace metals are mainly of chromium, lead, cadmium, copper, nickel, zinc and tin. Whereas, the major alkaline metals oxides for dry and wet base, which is essential for clinker formation, constitute 5.13% and 2.04% respectively, mainly of oxides of aluminum, calcium, sodium potassium and silica (see table 21).

4.5. Operational characteristics of the reference cement plant

In general, optimal substitution rates of fossil fuel by solid waste material can only be achieved if the process and the burning technology is tuned and adapted to the requirements that arise through the use of the solid waste material.

The following operational characteristics and restriction of the cement plant are often considered by several researchers as decision variables for objective and constraint setting in the evaluation of waste fuel substitution optimization (Westerlund,1989; Carpio *et al.*, 2008; Ioannis *et al*., 2011):

- Clinker production capacity and oxide composition requirement
- Kiln technology including favorable ignition and burn-out conditions for the solid waste material burring.
- Chemical composition of raw mix and cost of raw material
- Specific heat consumption or thermal energy demand
- Fuel requirement and current fuel characteristics and cost

One objective of this study was to examine the operational characteristics of the cement plat that was chosen for solid waste material substitution. This section discusses the above mentioned operational characteristics of the referenced cement plant. The results presented herein were based on the actual data collected from the cement plant.

The referenced cement plant namely “NCSC’s 3000tpd cement plant “is geographical located in east Ethiopia between N 09034.050' and E 041051.747'. As shown in figure 6, it is located 6km south of DDCA, which is the source for the solid waste material or fuel. The boundary of the plant is about 120ha, of which 40.1ha is used for plant facility and the rest 79.6 hectares is limestone mining area.

4.5.1. Production technology of the plant

The Plant operates on base of dry process technology and produce 3000 ton of clinker per day. The system is established with Φ4.3×62m rotary kiln and with 6-stage cyclone pre-heater and precalciner.

The kiln system is designed with two burning point: one located at kiln outlet and the other at pre-calciner inlet. The burners for kiln firing and precalciner firing is designed for multi fuel firing with low NOx burner of multi-channel. The burners have start up facility with diesel. The kiln also furnished with an electrical operated, automatic ignition system. Each of the burner stationed in kiln and precalciner have a standby.

The design heat consumption of clinker is 750Kcal/kg-cl or 3138KJ/kg-cl. The exhaust gas with a temperature of around 330° C is designed to use for raw material drying. Clinker burning system has been design to runs for 310 days per year which can makes the annual utilization ratio equal to 84.93%. Because of this, the annual clinker output has been assumed 930000 tons and the corresponding annual cement output has been also assumed 1400000 tons.

One of the most important modifications that a cement plant must make for waste co-processing is to install a burner that can handle both traditional primary fossil fuels and waste-derived fuels (WBCSD 2005). This would often increase fixed capital investment required for implementation of co-processing in running cement plant unless the plant design already equipped with multi fuel firing technology from the beginning. Since the plant is already designed with multi fuel firing, no installation of new burning technology is required.

The appropriate points for feeding waste fuel to the kiln system in relation to temperature and residence time depend on the kiln design, type, and operation. The feed point should be selected according to the nature of the waste fuels (WBCSD 2005). Waste with VOCs may be introduced at the main burner, in mid-kiln, in the riser duct, or at the precalciner but should not be introduced with other raw materials except where tests demonstrate that this will have no effect on the off gas (WBCSD 2005). For the case of NCSC’s cement plant, the existed kiln and precalciner fuel feeding point can be considered without the need for creating additional feed point and fuel firing technology installation.

In order to control air emission, the plant is equipped with the most recent and state of art technologies like Bag house, Electrostatic precipitation and fabric filter to capture particulate matter from the flue gas, this is also controls emissions of most volatile heavy metal and gaseous pollutants. Besides that, the plant has continuous emissions monitoring system to determines gas or particulate matter concentrations or emissions rates using computerized gas analyzer to measure and produce a results in units of the applicable emissions limit or standard. It provides a real time process emissions data, either to demonstrate environmental compliance or to control and optimize plant processes.

4.5.2. Thermal energy or fuel requirement & consumption

Thermal energy demand is the specific thermal energy demand for production of one kg of clinker. The designed thermal demand of the plant kiln is about 750Kcal/kg-cl or 3138KJ/kg-cl. Accepted maximum size of the coal is 300mm. kiln feeding size is below 30mm.

Currently, only imported coal from South Africa, as shown in table 22 bellow, has been utilized to meet the thermal demand. For production of 3000-ton clinker, the plant consumes over 410,000 kg coal (with NCV of 6000kca/kg) in daily base. Fuel to clinker ratio often consider at 13.5%. The cost of imported coal as it reaches to the plant (which includes purchasing price, freight and inland transport, loading and unloading) is around birr 5300 per ton coal having calorific value of 6000kcal/kg. This indicates that fuel bill is around 2.17 million birr per day. The plant is designed for solid and liquid fuel firing and feeding system. The following table shows cost and ultimate and proximate analysis of imported cola from South Africa.

Table 22: Cost and ultimate & proximate analysis of imported coal from South Africa

Component	Unit	Amount in unit
Unit Cost	Birr/ton	5300
Calorific Value	kcal/kg	6000
proximate analysis		
MC	%in 1-kg of coal	3.1
Ash	%in 1-kg of coal	14.5
Volatile matter	%in 1-kg of coal	27
Fixed Carbon	%in 1-kg of coal	55.4
Total	%in 1-kg of coal	100
Ultimate analysis mass% dry material		
Carbon	%in 1-kg of coal	67.02
Hydrogen	%in 1-kg of coal	4.2
Oxygen	%in 1-kg of coal	1.7
Nitrogen	%in 1-kg of coal	8.8
Sulphur	%in 1-kg of coal	0.68
MC	%in 1-kg of coal	3.1
SiO_2	%in 1-kg of coal	6.53
Al_2O_3	%in 1-kg of coal	4.21
Fe_2O_3	%in 1-kg of coal	0.62
CaO	%in 1-kg of coal	1.15
MgO	%in 1-kg of coal	0.39
K_2O	%in 1-kg of coal	0.07
Na_2O	%in 1-kg of coal	0.10
SO_3	%in 1-kg of coal	0.41
Other heavy metal	%in 1-kg of coal	1.03
Total		100

4.5.3. Raw material chemical composition requirement and consumption

Limestone, coal, clay, rhyolite, and gypsum is used as a primary input for part of raw mix preparation. The raw mix make up currently applied for clinker making (with 100% coal usage) entails 77%-Limestone and 23%-Clay. Table 23 shows the current chemical compositions of the main raw material -limestone, and clay. The raw materials are extracted from in plant quarry site (limestone) and an off-plant quarry site:10km away from the main plant. The proportion of clinker in cement mix is around 65%. The rest 35% is additive or blends like gypsum and rhyolite. Whereas, raw material feed to clinker ratio is of 1.6 to 1 i.e. for a production of 1kg of clinker 1.6 kg of raw material is used as limestone, clay and coal (as fuel). As part of the additive material mix, the proportion of gypsum and rhyolite for cement mix is limited at 5%-gypsum and 30%-rhyolite. Unit cost of raw material per kg is birr 15 for limestone and birr 45 for clay. The cost was calculated based on expenditures over consumption for the corresponding raw material. In case of limestone, the expenditure involves operation costs such as electric or fuel cost, labor cost, royalty cost, and maintenance cost of heavy duty quarrying machinery. Whereas, the expenditure for clay includes additional transportation cost. The reason for higher cost of clay compare to limestone is associated with the transportation cost of supplying the clay to production from 10km distance.

Table 23:The chemical composition of limestone and clay

Raw material	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Cost birr per ton
Clay (%)	17.45	47.86	12.12	6.71	10.43	2.50	45
Lime stone (%)	41.52	3.98	0.82	0.76	50.96	1.18	10

4.5.4. Clinker product requirement and composition

Since 1945, NCSC has been known by producing high quality Portland cement and blended pozzolan cement for different construction work. It is produced from a mixture of raw materials containing oxide, such as lime ($CaCO_3$), silica (SiO_2), alumina (Al_2O_3) and iron (Fe_2O_3). The clinker is the basic part for production of Portland and pozzolan cement. The quality of clinker (and thus, of the cement produced from it) are mainly determined by its mineral composition and its structure. The chemical and mineralogical composition of NCSC's clinker product is highlighted in Table 24.

Table 24: Chemical composition in clinker (product specification)

Parameter	Limit value
CaO	55 -65%
SiO_2	20 -25%
Al_2O_3	5-16%
Fe_2O_3	3-10%
Alkaline (Na_2O, K_2O)	<1%
SO_3 & heavy metal	<0.2%
Mg2O	<3.5%
LSF	0.9-.98
SR	2.2-2.8
AR	1-1.75

The main chemical composition in clinker chemistry are Tri-calcium silicate or Alite (3CaO x SiO_2 or C3S), Di-calcium silicate or Belite (2CaO x SiO_2 or C2S), Calcium aluminate or aluminates (3CaO x Al_2O_3 or C3A) and Calcium ferrite or ferrites (4CaO x Al_2O_3 x Fe_2O_3 or C4AF). The rest element such as the alkalis, sulfur and chlorides are volatilized at the high temperatures in the kiln system resulting in a permanent internal cycle of vaporization and condensation ("circulating elements"). Despite the absence of recorded data, it is assumed that the large part of these elements normally either being remain in the kiln system or leave the kiln with the clinker. Only a small part is expected to be emitted into environment as part of kiln exhaust gases. As shown in table 24 there is no a specific value for each chemical and mineralogical composition of clinker. Each of which has an upper and lower limit value which can be consider as a limit factor for raw mix consideration and product quality control.

4.6. Optimal substitution rate of SWM

As coined by several research, the use of SWM either as raw materials or fuel substitution, allows reduction in the final product cost. This fact contributes as a partial solution for the industrial and municipal waste disposal problems. SWM substitution also provides additional revenue for the cement factories, either due to their low acquisition costs, or due to the payment received for the service of thermal waste destruction or carbon emission reduction. However, fuel substitution by SWM must be subject to the desired final product quality and operational restriction, which is the most important control parameter in the cement Portland production. When SWM are used as fuel substitution in the rotary kilns, the generated ashes replace some of the components of the raw materials, and therefore these ashes must be made compatible with the remaining raw materials, in order to be absorbed in high percentage in the clinker matrix (Carvalho, 1997). Gaseous emissions from the kiln system released to the atmosphere are the primary environmental concern in cement manufacture today. Major gaseous emissions are NOx and SO_2. Other emissions of less significance are VOCs (volatile organic compounds), CO, ammonia, HCl, and heavy metals. CO_2 as the main greenhouse gas is released in considerable quantities. When SWM are used as fuel substitution in the rotary kilns, the physical and chemical reactions of the raw material with fuel release oxides of carbon, sulfur and nitrogen which is responsible for environmental quality problem or gaseous atmospheric emissions. The percentage chemical composition of fuel can be considered as one factor. But it also further rely on chemical composition on raw material, operational and combustion condition (CEMBUREAU, 1999). NOx formation is an inevitable consequence of the high temperature combustion process, with a smaller contribution resulting from the chemical composition of the fuels and raw materials. Sulphur entering the kiln system via raw materials and fuels is largely captured in the kiln products. However, sulfur contained in raw materials as sulfides (or organic sulfur compounds) is easily volatilized at fairly low temperatures (i.e. 400-600° C) and may lead to considerable SO_2 emissions in the stack. Carbon dioxide emissions arise from the calcination of the raw materials and from the combustion of fuels. Emissions of CO_2 resulting from fuel combustion can reduced due to alternative fuel substitution or fuel switch. CO_2 resulting from calcination can be influenced to a very limited extent only.

The decision of SWM substitution in cement plant as coined by number of literatures is depend on lots of criteria. However, for this study only major criteria such as production cost, operational restriction and product specification were considered for specific case of NCSC’s 3000tpd cement plant fuel substitution. All of these criteria is further depend on the chemical and elemental composition of the raw material and fuel ash constituents, specific heat consumption and availability of the fuel.

Models for such case, especially in the cement industries, are usually based on knowledge about the chemical composition of the product and combustion process in kiln system. These models are, in a practical environment, mainly used for obtaining best possible feed rates of the raw materials and fuel simultaneously, while satisfying the criteria.

The problem of selecting the optimal rate alternative fuel substitution considering operational restriction and environmental limit is discussed in detail with case specific problem in paper of

Ioannis *et al*. (2011). Where the decision of optimal rate of multiple alternative fuel with different raw material is computed based on a Mixed Integer Linear Program problem. Where the cost of raw materials is minimized and several operational constraints are satisfied. Similarly, Carpio *et al.* (2008) present an optimization based framework for the selection of both raw material and fuels that include one alternative fuel, namely TDF. Where the decision of best possible solution is evaluated based on linear problem for raw material and fuel mix.

This section presents the results of optimal rate of fuel substitution based on mathematical model formulated by Ioannis *et al*. (2011) and Carpio *et al.* (2008). Both Authors present an optimization based framework for the selection of raw material and fuels that include alternative fuel. In selecting the best possible mix, they compute all inputs parameters (raw material, fossil fuel and alternative fuel) simultaneously. All the mathematical formulation presented in this studies were also managed in the same way that of the two studies.

A mathematical models based on material balance and energy requirement are used to select raw materials and fuels simultaneously. Then after, other environmental and operational parameter is evaluated to see the change. The selection of the best possible solution is optimized based on economic function define by unit cost of the raw material and fuel. The cost of SWM includes the fixed capital investment and operation & maintenance cost required for SWM homogenized and stabilizing facility (pre-processing plant) establishment and operating.

4.6.1. Optimization model problem definition

The mathematical model is a linear problem that can be solved by linear programing or optimization algorithms. The aim is to find best possible solution, while satisfying product specification or quality requirement (which is related to clinker) and operational restriction, by reducing of clinker production cost up on fuel cost reduction. In the work of Carpio *et al.* (2008) major operational and product specification limiting factor is listed for defining decision variable and setting objective and constraint. This study as well considers these factors with further assumptions as shown below:

- The amount of oxide and heavy metal element presented in fuel ash may affect the quality of clinker through material and fuel chemical composition. It is assumed that generated ash during fuel combustion left the kiln with the clinker. So clinker product as well as quality is the function of chemical composition of fuel and raw material, which includes oxides, alkaline and heavy metal.

- The amount of alkaline presented in the fuel is an operational limiting factors that may affect operation of the kiln by building circulation air in kiln system and cause dust formation. So operational restriction is function of alkaline.
- Other compound and element presented in the fuel and raw material is assumed to be used for combustion and left the kiln as exhaust gases or flue gas.
- The production cost of clinker is a product of raw material and fuel cost. So the cost of raw material & fuel may affect the rate of substitution as well as the production cost. The electric cost for rotary kiln is assumed constant with change in fuel type.

So, evaluation of optimal rate of fuel substitution for this study takes into account the above mentioned product specification, operational restriction and production cost assumption. SWM, which is homogenized and stabilized by pre-process technology, was assumed to feed in different rate of thermal substitution. The model accordingly finds on the most profitable selection of raw materials, fossil fuels and SWM feed in order to minimize clinker production cost (which is a function of fuel and raw material cost) while meeting operational restriction and product specification.

4.6.2. Optimization model formulation

The model formulation considers simultaneous selection of exciting raw materials, fossil fuels and SWM fuel to be fed in specific cement facility. The mathematical model consists of material and energy balances that are expressed as equality constraints and product specification constraints that are expressed as inequality constraints.

Model index

While describing the optimization framework objective function & constraint, the following subscript and superscript indices is specified for each decision variable as outline below:

- j = Raw Materials (RM): which includes limestone, Clay, basalt
- l = Fuels (F) includes as Fossil Fuel (FF): Coal and as Alternative Fuel (AF): SWM
- i = Oxides: such as SiO_2, Al_2O_3, Fe_2O_3, CaO,
- k = Alkalis such as K_2O, Na_2O

- s (SO_3) = Sulfur (SO_3)
- n = Heavy Metals such as Hg, Tl, Cd, ...

Objective Function

As shown in equation (2), the objective function considered minimize cost of clinker production consists of two parts. The first part is the cost of raw materials. The second part is the cost of fuels (traditional fossil fuels and SWM). Thus, the objective function (in birr/kg of clinker) to be minimized can be written as:

$$z(cost) = \left(\sum_{j\,(RM)=1}^{\infty} UC_j^{RM} * m_j^{RM} \right) + \left(\sum_{l\,(F)=1}^{\infty} UC_l^{F} * m_l^{F} \right) \text{……. equation (2)}$$

- Where m_j^{RM} & m_l^F are mass of raw materials and fuel component per kg of clinker produced respectively used in clinker production.
- Where UC is the cost per unit of raw material or fuel in birr/kg dry material. The UC for raw material is the sum of quarry operation costs such as electric or fuel cost of quarry operation, labor cost, royalty cost, maintenance cost of heavy duty quarrying machinery, and transportation cost. The UC for fossil fuel is the sum of purchasing cost of the fossil fuel, transportation cost and loading and unloading cost. The UC for SWM is the sum of the annualized fixed capital investment cost and the variable cost associated with the use of SWM fuel as a fossil fuel substitute.

Mass Balance (Equality) Constraint

Mass balance constraint simply says that the amount of clinker produced must be equal to 1kg. As shown in equation 3, this constraint is expressed the material balances of the most important raw material and fuel constituent such oxides, alkalis, sulfur (expressed as SO_3) and heavy metal element should be expressed using a basis of 1kg of clinker produced.

$$= \sum_{i=oxides}^{\infty}(m_i^C) + \sum_{k=Alkalis}^{\infty}(m_K^C + m_{SO3}^C) + \sum_{n=Heavy\ Metals}^{\infty}(m_n^C) = 1kg\text{……eq equation (3)}$$

- Where m_i^C is the mass of oxide-(i) in the clinker in kg (i)/kg clinker obtain from the mass fractions of the corresponding oxides in the raw materials and fuels. More specifically the material balance of m_i^C can be further calculated as:($\sum_{j=RM} \omega_{ij}^R * m_j^R + \sum_{l=F} \omega_{il}^F * m_l^F$). Where ω_{ij}^R and ω_{ij}^F are the mass fractions of corresponding oxides in the raw materials (m_j^R) and fuels (m_l^F). It is assumed that the fuel ash is fully incorporated in the clinker produced. As a result, the mass fractions of the oxides in the fuel are calculated by multiplying the mass fraction of the oxides in the fuel ash and the mass fraction of the ash in the fuel.

- Where m_k^C is the mass of alkalis-(k) in the clinker in kg (k)/kg of clinker obtain from the mass fractions of the corresponding alkalis in the raw materials and fuels. More specifically Material balance of m_k^C can be further calculated as:($\sum_{j=RM} \omega_{kj}^R * m_j^R + \sum_{l=F} \omega_{kl}^F * m_l^F$). Where ω_{kj}^R and ω_{kj}^F are the mass fractions of corresponding alkies in the raw materials (m_j^R) and fuels (m_l^F).
- Where m_{SO3}^C is the mass of sulfur expressed as SO_3 in clinker. material balance of m_{SO3}^C is calculated through the formula of :($\sum_{j=RM} \omega_{SO3j}^R * m_j^R + \sum_{l=F}(\omega_{SO3l}^F * m_l^F)$). Where ω_{SO3j}^R is the mass fraction of SO_3 in raw material (j). where ω_{SO3l}^F is the mass fraction of SO_3 in fuel (l). The mass fraction of the SO_3 in a fuel is calculated by expressing the S in wt.% as SO_3 (using the formula (80/32) (%S/100)).
- Where m_n^C is mass of heavy metals in clinker in kg(n)/kg of clinker. Material balance of m_n^C can be further calculated by:($\sum_{j=RM} \omega_{nj}^R * m_j^R + \sum_{l=F} \omega_{nl}^F * m_l^F$). Where ω_{nj}^R is the mass fraction of heavy metal in raw material (j). where ω_{nl}^F is the mass fraction of heavy metal in the fuel (l). In the above equation, it is assumed that clinker is a perfect sink for the bulk of the heavy metals added to the kiln system. It is known that, apart from mercury, selenium and thallium, all heavy metals are almost perfectly (>99%) absorbed by clinker or cement kiln dust Klipspringer and Achternbosch et al. (2003), cited by Ioannis *et al.* (2011). In any case, the amount of heavy metals is the maximum amount that can be incorporated into the clinker for the selected raw materials and fuel mix.

Specific heat consumption constraints

This constraint simply says that energy required for producing 1 kg of clinker must be satisfied according to the design parameters of thermal heat requirement. The total energy demand should assist the heat specific consumption presented as equation (4)

$$\sum_{l=fuel}(m_l^F * NCV_l) = TED \text{.........} \text{ equation (4)}$$

- Where NCV is the net calorific value of the fuel (in kJ/kg fuel)
- Where TED is the specific (per kg of clinker) thermal energy demand.

The use of SWM as a supplemental fuel for different case or rate of SWM substitution is define by thermal substitution rate as expressed in equation (5) below. This equation normally used to see the change of value at different rate of fuel substitution.

$$\sum_{l=SWM\,fuel}(m_l^F * NCV_l) \leq TED * (\frac{TSR}{100}) \text{......... equation (5)}$$

Product Quality Constraint

Satisfying the pre-specified quality requirements or product specification is an important Parameters in such kind of optimization problems. The necessary information when solving this optimization problem is estimated by the specified product properties from the chemical composition of the product and the compositions of the raw materials used for producing the product. Furthermore, the lower and upper limits for the amounts of the corresponding raw material feeds as well as for the properties must be known (WESTERLUND, 1987).

In a cement kiln, raw meal oxides like CaO, SiO_2, Fe_2O_3, and Al203 react to product cement clinker. The clinker contains basically tricalcium silicate (C3S), dicalcium silicate (C2S), tetracalcium alumino ferrite (C4AF), tricalcium aluminate (C3A). Chemical analysis of cement and clinker can be as well expressed in terms of semi-theoretical indices or mixture module:

- Alumina ratio (or modulus) AR = Al_2O_3: / Fe_2O_3
- The silica ratio (or modulus) SR = $SiO_2/(Al_2O_3 + Fe_2O_3)$
- lime saturation factor LSF = $CaO/(2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.65\ Fe_2O_3)$.

A mass balance between the cement clinker compounds and the corresponding oxides from the raw material and fuel feed can be used for chemical analysis and constraint formulation. In all form, the chemical composition of cement clinker must satisfy the value between the upper and lower limit value according to the product specification of the cement plant. Accordingly, three approach can be used in setting quality constraint: one based on oxides concentration in corresponding raw material & fuel in relation to the chemical composition of clinker; the other based on semi-theoretical indices or mixture module of lime saturation factor, silica and alumina ratio and the other based on Bogue calculation (which is used as an indicator of the chemical composition of the clinker and express the likely quantitative phase composition as a linear function of the oxides present in the clinker) (WESTERLUND,1987; Carpio *et al.,* 2008; Ioannis *et al*., 2011). All are alternatively used in the cement industry in order to specify the properties of the product. However, for this study the first two clinker quality indicators were applied for quality restriction formulation. Equations (6) to (8) are the restrictions of the mixture control modules regarding to the clinker quality (Carpio et al., 2008). Whereas equation (9) are oxide composition restriction of clinker with operational restriction (alkaline).

Constraints on alumina ratio (AR)

$$AR_L \leq \frac{m^c_{Al_2O_3}}{m^c_{Fe_2O_3}} \leq AR^U \text{………… equation (6)}$$

where subscript L indicates a lower bound and superscript U an upper bound for aluminum ratio (AR) testing. Where is $\frac{m^c_{Al_2O_3}}{m^c_{Fe_2O_3}}$ related to the ratio of aluminate to ferrite phases of clinker which has a significant impact on cement properties. But, this equation is a nonlinear function. To run the optimization model, the above equation has been converted to a linear function as shown below:

For lower bound, the equation is expressed as:

$$\sum_{j \in Raw\ Materials} (-\omega^R_{Al_2O_3j} + AR_L \omega^R_{Fe_2O_3j}) m^R_j + \sum_{l \in feuls} (-\omega^F_{Al_2O_3l} + AR_L \omega^F_{Fe_2O_3l}) m^F_l \leq 0$$

For Upper bound, the equation is expressed as:

$$\sum_{j \in Raw\ Materials} (\omega^R_{Al_2O_3j} - AR^U \omega^R_{Fe_2O_3j}) m^R_j + \sum_{l \in feuls} (\omega^F_{Al_2O_3l} - AR^U \omega^F_{Fe_2O_3l}) m^F_l \leq 0$$

Constraints on silica ratio (SR)

$$SR_L \leq \frac{m^c_{SiO_2}}{m^c_{Al_2O_3} + m^c_{Fe_2O_3}} \leq SR^U \text{ ………… equation (7)}$$

where subscript L indicates a lower bound and superscript U an upper bound for silica ratio (SR). Where $\frac{m^c_{SiO_2}}{m^c_{Al_2O_3}+m^c_{Fe_2O_3}}$ is proportion of calcium silicate property with aluminate and ferrite phases of clinker. The linearized equation is shown as follow:

For lower bound, the equation is expressed as:

$$\sum_{j\in Raw\ Materials}(\omega^R_{SiO_2 j} - SR^U(\omega^R_{Al_2O_3 j} + \omega^R_{Fe_2O_3 j}))m^R_j + \sum_{l\in feuls}(\omega^F_{SiO_2 l} - SR^U(\omega^F_{Al_2O_3 l} + \omega^F_{Fe_2O_3 l}))m^F_l \leq 0$$

For Upper bound, the equation is expressed as:

$$\sum_{j\in Raw\ Materials}(-\omega^R_{SiO_2 j} + SR_L(\omega^R_{Al_2O_3 j} + \omega^R_{Fe_2O_3 j}))m^R_j + \sum_{l\in feuls}(-\omega^F_{SiO_2 l} + SR_L(\omega^F_{Al_2O_3 l} + \omega^F_{Fe_2O_3 l}))m^F_l \leq 0$$

Constraints on lime saturation factor (LSF)

$$LSF_L \leq \frac{m^c_{CaO}}{2.8\ m^c_{SiO_2}+1.2m^c_{Al_2O_3}+0.65m^c_{Fe_2O_3}} \leq LSF^U \text{ .... equation (8)}$$

where subscript L indicates a lower bound and superscript U an upper bound for lime saturation factor (LSF). LSF relates the ratio of Alite (tri-calcium silicate) to Belite (Di-calcium silicate) and indicates whether an unacceptable level of free lime can be present in clinker.

For lower bound, the equation is expressed as:

$$\sum_{j\in Raw\ Materials}(-\omega^R_{CaO j} + LSF_L(2.8\ \omega^R_{SiO_2 j} + 1.2\omega^R_{Al_2O_3 j} + 0.65\omega^R_{Fe_2O_3 j}))m^R_j$$
$$+ \sum_{l\in Fuels}(-\omega^F_{CaO l} + LSF_L(2.8\ \omega^F_{SiO_2 j} + 1.2\omega^F_{Al_2O_3 j} + 0.65\omega^F_{Fe_2O_3 j}))m^F_l \leq 0$$

For Upper bound, the equation is expressed as:

$$\sum_{j\in Raw\ Materials}(\omega^R_{CaO j} - LSF^U(2.8\ \omega^R_{SiO_2 j} + 1.2\omega^R_{Al_2O_3 j} + 0.65\omega^R_{Fe_2O_3 j}))m^R_j$$
$$+ \sum_{l\in Fuels}(\omega^F_{CaO l} - LSF^U(2.8\ \omega^F_{SiO_2 j} + 1.2\omega^F_{Al_2O_3 j} + 0.65\omega^F_{Fe_2O_3 j}))m^F_l \leq 0$$

Constraints on clinker's oxide composition

$$m_{L,i}^{C} \le m_i^{C} \le m_i^{C,U} \ldots\ldots\ldots\ \text{equation (9)}$$

Where U and L represent the upper and lower bound of oxides, alkaline and heavy metal present in clinker.

Fuel supply Constraint

This constraint defines the maximum and minimum amount of available fuel per kg of clinker produced as shown in the following equation.

$$m_{L,l}^{F} \le\ m_l^{F} \le\ m_l^{F,U} \ \ldots\ldots\ldots\ \text{equation (10)}$$

Where $m_l^{F,U}$ is the maximum amount of fuel that is available per kg of clinker produced (it can be calculated by dividing the total amount of the fuel available by the plant capacity). $m_{L,l}^{F}$ is the minimum amount of fuel that has to be consumed. This can be zero but normally, for strategic reasons, a minimum nonzero amount should be selected in order to support a sustainable market for the alternative fuel considered (and possibly reduce plant dependency on a restricted set of energy supply options).

4.6.3. Input parameters for optimization problems

In order to optimize the model that is presented so far, both primary information that is discussed in previous section including some other secondary data particularly unit cost of fuel were used as input parameter.

Input parameter for objective function decision variable

In order to minimize clinker production cost (which is a function of fuel and raw material cost), the decision variables for objective function (reference to equation 2) are unit cost of raw material and fuel that include fossil fuel and Alternative fuel. Table 22 and 23 provides the current unit cost of limestone, clay and coal collected from NCSC's 3000tpd cement plant.

However, the unit cost of SWM is define based on calculating the fixed capital investment costs and operating costs Tchobonoglous & Frank (2002). But, there are several ways in which the economic performance of SWM fuel is commonly expressed. This study more concerned about the cost of producing a kg of SWM fuel suitable for fuel substitution in cement kiln. Hence the cost/kg of SWM is a better economic indicator. Fuel demand specification and the characteristic SWM is a critical factor in deciding the pre-processing facility setup and plant modification. Taking this into consideration, it is possible to determine the Fixed capital investment cost (C_i) and operation and maintenance cost ($C_{O\&M}$) required. Accordingly, the unit cost of SWM fuel produced is expressed

$UC = \frac{C_a + C_{O\&M}}{SWM_a}$..........equation (10)

- Where $C_{O\&M}$ is the annual operation and maintenance cost and SWM_a is the annual SWM Fuel produced.
- Where C_a is annual capital cost it is expressed $C_a = C_i * CRF(i, n)$
- where C_i is the total investment cost, i is the interest rate (in fraction) and n is the payment period (in years).
- Where Capital recovery factor (CRF) is given as: $CRF_{(i,n)} = \frac{i(1+i)^n}{(1+i)^n - 1}$

The assumption considered in cost estimation includes: the interest rate (i) was 12% (which is based on the current national bank interest rate); payment period (n) was 15 years (this is assumed based on MoHUA (2018)). Annual SWM fuel produced was estimated based on the dry weight combustible fraction of SWM generated from DDCA, which is 68.77 ton per day (see table 20 section 4.4.1). Hence, the annual SWM fuel produced (SWM_a) considering 310 operating days per year was estimated over 21318.7 ton per year.

According to MoHUA (2018), the investment costs is the sum of capital costs for setting up alternative fuel conditioning and engineered fuel production plants, and capital cost for storage and feeding mechanism (retrofitting) of processed SWM fuel at cement plants. The typical investment cost (C_i) was estimated over birr 58 million for 100tpd plant with 25mm particle size and below 15% moisture content. This plant would have process units such as 1) size reduction unit; 2) size separation unit: which is used to separate material by size and shape, and for removing glass; 3) magnetic field separation unit: which is used to separate ferrous or magnetic materials from nonmagnetic materials; 4) densification (compaction) unit: which is used to increase the density of recovered materials inorder to reduce transportation costs and simplify storage; 5) drying unit: which is used for moisture reduction via thermal drying. The plant was considered to be established close to the existing landfill site of DDCA. Other cost such as tax and land lease was assumed to be zero as part of cost sharing approach with the municipality.

The typical operation and maintenance cost ($C_{O\&M}$) as estimated by MoHUA (2018) was over birr 3109 per ton of processed SWM fuel. The cost estimation considers the sum of the cost of energy consumption; costs of personnel; costs of maintenance (machinery and buildings) and cost of transportation and handling of the processed SWM fuel. Here waste collection and transportation cost was assumed to be covered by the municipality.

Hence considering all the above mentioned input parameters, the unit cost of SWM fuel (UC) was estimated over birr 3509 per ton of SWM fuel as shown in table 25 below.

Table 25:Unit cost of pre-processed SWM

Variables	Unit	Input & result
Investment cost (Ci)	Birr	58140000
Interest rate(i)	%	0.12
Payment period (n)	year	15
Capital Recovery Factor (CRF)		0.146824
Capital Cost (Ca)	Birr	8536361
Cost of Operation and Maintenance (C o&m)	Birr	66285168
Annual SWM Fuel produced (SWMa)	ton	21318.7
Unit Cost SWM (UC)	Birr	3509.667

Input parameter for mass balance constraints

The percentage composition of oxides, alkaline, sulfide and heavy metal in the corresponding raw materials and fuel in dry base is presented in table 23 (section 4.5.3), table 22 (section 4.5.2) and table 21 (section 4.4.3).

Input parameters of Specific heat consumption (equality) constraints

The net calorific value (NCV) of the corresponding fuels (coal and SWM) in dry base is presented in table 20 (section 4.4.2) and table 22 (section 4.5.2). Whereas the thermal energy demand (TED) as discussed in section 4.5.2. is 750Kcal/kg-cl or 3138KJ/kg-cl.

Input parameters of Product Quality Constraint

Section 4.5.4 and table 24 present the product specification for clinker base.

4.6.4. Optimization result

Micro-soft excel solver was used to solve the linear problem from equation (2-10) the solver feasibility report is attached in Annex 8. To see the change that would happen when SWM substituted, the solver run for two feeding rate: first at a ratio of 100% coal and 0% SWM i.e. without SWM substitution; second at a ratio of 13% SWM and 87% coal feeding ratio i.e. for possible maximum SWM substitution rate. Table 26 summarize the result of the optimization problem for both feeding rate. cost savings of around birr 37464.00 per day or 12 million per annum was predicted, while satisfying the product quality specification and operational restriction.

As clearly indicated in table 26, at 13% substitution of coal with SWM, the amount of coal required for fuel and raw mix formation was decreased by 13% but the quantity of limestone required for raw mix design decreased with insignificant fraction. on contrary, the amount of clay required for raw mix design increased by insignificant fraction. On the other hand, SR of the raw mix increased fractionally, whereas LSF and AR decreased only slightly. At the same time, the overall raw material to clinker ratio slightly increased by about 0.011 fraction.

Table 26:Summary of optimal fuel & material mix at 0% & 13% rate of SWM substitution

TSR	%	SWM Substitution rate	
		0%	13%
Mass of Coal	Kg/kg-cl	0.125	0.108
Mass of SWM	Kg/kg-cl	0.000	0.021
Mass of limestone	Kg/kg-cl	1.204	1.203
Mass of Clay	Kg/kg-cl	0.334	0.336
SR		2.455	2.462
AR		1.719	1.709
LSF		0.939	0.938
Total cost	birr/kg-cl	0.689	0.677
RM to Clinker ratio		1.666	1.670
limestone ratio	%	72.401	72.073
Clay ratio	%	20.085	20.162
Coal ratio	%	7.515	6.511
SWM ratio	%	0.000	1.254

In general, no significant variation in all product specification parameter was detected at 13% substitution rate of SWM and hence no additive for the raw mix design would be required to achieve the product quality requirement. It is important to note that the variation observed in all product specification parameter was found within the upper and lower bound restriction. The values are barely distinguishable from (Mustafa Kara, 2013; Ioannis *et al*., 2011) who found that a significant economic benefit from fuel cost saving and emission reduction revenue, while satisfying product quality specification and operational restriction. If carbon emission reduction revenue considered as Ioannis *et al*. (2011) and Mustafa Kara (2013) the value further increase the economic benefit by 13%.

The side effect on environment and mass of air required was attempt to investigate by applying thermochemical equations of combustion Tchobanoglous et al. (2002). Table 27 summarized the result. With 10% Excess air, the mass of air required at 100% coal fuel use is estimated over 2.077kg per kg of clinker produce. While at 13% SWM fuel substitution, the mass of air required for combustion was decreased by 0.17kg/kg of clinker produced. Emissions of CO_2 and SO_2 specific to fuel were also decrease by .0.02kg per kg of clinker produced. Emission of CO_2 from raw material did not appear to be varied.

Table 27: Possible effect on other environmental and operational parameter

Parameters	Coal at 100 % use	SWM at 13% substitution
CO_2	0.307175	0.28
H20	0.051125	0.06
SO_2	0.0017	0.0015
O_2	0.21372403	0.20
N_2	1.59975544	1.47
Mass of air required @ 10% excess air	2.07760446	1.91
CO_2 emission from Raw material	51.1544688	51.14

The finding with regard to mass air demand are in contradiction with the result obtains by Ioannis *et al*. (2011). Although the results differ considerably from that of Ioannis *et al*. (2011), it can nevertheless be argued that the presence of high oxygen in the SWM may affect the mass of air demand.

With regard to the reduction of CO_2 and SO_2 emission, the value agrees fairly well with some literature (Mustafa Kara, 2012; Azad Rahman *et al., 2013;* Ioannis *et al*., 2011) and further support the role of SWM substitution for emission reduction and air quality.

5. CONCLUTION AND RECOMEDATION

5.1. Conclusion

Understanding the quantity and characteristics of solid waste is essential in order to plan for fuel substitution. Knowing the elemental composition of solid waste material is also relevant to estimate the calorific value and excess air requirement during combustion. Knowing the ash content of the given solid waste material also assists to define the clinker chemical property. In this regard, the waste study was performed in DDCA. Optimal rate of fuel substitution was done for specific case NCSC's cement plant.

In this study, the data obtained from residential unit and non-residential unit are used to estimate the total quantity and characteristics of the waste. The findings revealed that the daily per capita waste generation rate is estimated over 0.43kg for residencies unit and 1.29kg for business unit. Thus, these was translated to overall waste quantification in DDCA is about 262 ton of Solid waste per day. The finding of solid waste component shows that DDCA waste contains a combustible solid waste component of above 65%, taking into account of biomass, paper, plastic, food waste, bone, tire, rubber, textile and leather. The overall waste composition has higher percentage of energy recoverable waste (65.83%) compared to the non-recoverable material (34.17%). In terms of tonnage, this figure would suggest that an estimated 172.52 tons of energy recoverable waste material can found from DDCA.

Regarding to elemental, ash and heating value analysis, typical property data for the corresponding waste material was used to estimate the overall waste organic compound, ash and heating value. By using typical ultimate analysis data of the waste component, the amount of moisture in combustible waste fraction is estimated about 60%. Whereas the ash and volatile element of the combustible waste fraction that is supposed to be used for energy and material recovery is estimated around 40% or 68.77 ton per day. Where carbon and oxygen account for the largest fraction of 34%. By using the elemental composition of the combustible waste fraction determined before and empirical equation; the high heat value or net calorific value of the combustible fraction of waste component as received (wet weight) and dry base are estimated around 1798Kcal/kg and 4655Kcal/kg respectively.

Taking this information into consideration, SWM, which is homogenized and stabilized by pre-process technology, was theoretical developed for maximum and minimum feeding rate or thermal substitution, which is 0 and 13% fuel feeding rate. Optimization model was developed based product cost function subject to operational requirement, thermal energy demand and product quality constraint.

The result reveal that at 13% thermal substitution rate with coal at 87%, cost savings of around birr (37464.00) per day or 12 million per annum are predicted, while satisfying the product quality specification and operational restriction. In general, no significant variation in all product specification parameter was detected and hence no additive for the raw mix design would be required to achieve the product quality requirement at 13% substitution rate of SWM. The variation observed in all product specification parameter was found within the upper and lower bound restriction The side effect on environment and mass of air required is attempt to investigate by applying thermochemical equations of combustion. The finding shows that all parameter has positive implication to environment. This indicate that it is economically as well as environmental feasible for NCSC to substitute 13% of the cola by SWM generated from DDCA without affecting the product quality and operational problem.

5.2. Recommendation

In view of the research finding, the researcher believes that policy makers would make strategic decision to incorporate SWM fuel substitution as part of the climate resilient green economy strategy. It is also important to encourage or incentivized cement factories and municipal to be involved on solid waste material and energy recover options considering cement kiln as solid waste management option. Cost sharing approach is an important solution in minimizing the capital and operation cost burden. The need for strong cooperation and partnership between the regional government and the cement plant is vital as well in every stage of the project cycle. Further work on potential barriers need to be investigated more importantly focusing on reliability of supply, price elasticity, consistency, cost and Skepticism.

Analysis of physical and chemical parameters of interest for waste characterization, which are heating value, elemental and chemical composition of the combustible waste material, were made based on theoretical value of the typical material. Hence, further experimental tests on waste characterization particularly on heating value, elemental and chemical analysis are needed in order to establish statistically acceptable estimation. On a wider level, further research is also needed to determine the feasibility of SWM substitution with respect other environmental and operational constraint or limiting factors.

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ANNEX 1: QUESTIONNAIRE FOR SOCIO- ECONOMIC SURVEY FROM HOUSEHOLDS

1. Kebele: ___________ Village: ______________House number: ___________
2. Housing condition: (circle the appropriate one)
    a. Privet owned G+1 & above or fenced Villa made of concrete or stone or HB
    b. Condominium, government owned villa or apartment
    c. kebele's or privet owned house made of from wood & mud or stone & mud without cement or HB; may or may not be fenced with iron sheet or life fenced
3. Who is the head of the family?
    a. Name: _________________Gender: ____________Marital status: _________________
    b. level of education: ____________ Current occupation or profession: _____________
    c. Family size: ___________
4. To whom the house you are living is belongs? (circle the wright one)
    a) Own_____ b) Rented_______
5. If it is rented from whom you get rented?
    a. Private
    b. Kebele
    c. Housing Agency
    d. Privet or government Institution
6. How many Rooms does it have?____________________
7. What is your means of income: (circle the wright one)?
    a. Own business
    b. Employment
    c. Pension
    d. Remittance
    e. House Renting
    f. Other __________________
8. If you have run your own bossiness, what kind of business are you currently running?
9. If you are employed, which one is describe your employee?
    a. Public organizations
    b. Private organization
    c. Community based organization
    d. NGO's
10. Is there any of the family member engaged in any sort of income generating activity?
    a) Yes _____ b) No_____
11. If yes, how many member of the household are engaged? ___________ and What is their monthly income? ETB __________
12. What is your Family monthly income? ETB __________
13. What is your average monthly household expenditure? ETB__________

14. What are your main lines of expenditure?

a) Food items ETB ------ b) Clothing ETB ------- c) Schooling ETB ------

d) Health cost ETB ------ e) Energy cost ETB ----- f) water supply ETB --------

g) Communication ETB ------ h) Social cost ETB ----- i) Entertainment ETB ------

ANNEX 2: QUESTIONNAIRE FOR NATIONAL CEMENT SHARE COMPANY

1. Is there internal policy or plan that support the use of alternative fuel as part of emission reduction, environmental management, cost reduction and energy conservation (corporate strategy)
    a. If yes, how do you evaluate the implementation (under paper, planning, establishment or implementation)
2. Is there any criteria set by the company for alternative fuel use?
    a. Environmental related criteria
    b. Technical related criteria
    c. Economic related criteria
3. For what type of cement production specifically the plant is established for (OPC, PPC,)
4. What type kiln system installed and number of cyclone (____Pre-heater plus pre-calciner kiln & _____preheater kiln)
5. What makes special the installed kiln system?
6. Where is the fuel feeding point in the kiln system?
7. What are the thermal requirement at different heat consumption point?
8. What are the safety regulation in case of excess heat?
    a. The gas temperature at kiln inlet (<900 0C)
    b. Material Temperature at kiln outlet (<1250 0C)
9. For what type of fuel feeding the kiln system is primarily build?
    a. Solid fuel
    b. Liquid fuel
    c. Gaseous fuel
10. Does the existed kiln technology in place (involve) alternative fuel feeding system in case as an option for future use?
11. What is the thermal energy source (fuel) currently using for kiln burning including its cost Birr/kg?
    a. Coal
    b. Pet coke
    c. HFO
    d. Natural gas
12. What is the Raw Material (RM) composition currently using for clinker production including its cost Birr/kg?
13. What is the fuel and RM mix ratio for inputs?
14. What is the requirement for both receipt and burning of fuel & RM in terms of chemical & physical property?

Composition		Solid Fuel	Liquid fuel	Gaseous fuel	Limestone	Clay	Iron ore
GCV (J/kg)	max						

	min						
Moisture (%)	max						
	min						
Size	max						
	min						
Density	max						
	min						
Carbon (%)	max						
	min						
Nitrogen (%)	max						
	min						
Oxygen (%)	max						
	min						
Sulphur (%)	max						
	min						
Chlorine (%)	max						
	min						
SiO_2 (%)	max						
	min						
Al_2O_3 (%)	max						
	min						
Fe_2O_3 (%)	max						
	min						
CaO (%)	max						
	min						
MgO (%)	max						
	min						
K_2O (%)	max						
	min						

15. Do you have homogeneity requirement level? If yes, __________
16. What is the specific heat consumption of clinker? (_______ kJ/kg of clinker)
17. Is there enough space for alternative fuel feed stocking?
18. What technology and technique is applied to reduce emission of CO2, PM, SOx and NOx as well as energy consumption
19. Is there any other requirement to be complied for other than the nation and local environmental requirement? If yes, which international organization requirement?

ANNEX 3: QUESTIONNAIRE FOR NON-HOUSEHOLD UNIT SURVEY

15. Kebele: ___________ Village: ______________Tarde Reg. number: ___________
16. Type of business? ___________
17. Major activities or service in your business? __________
18. Is your business subject to seasonal variation? ________
19. Total acres of business establishment or running area? _________
20. Monthly water and electric bill? _______ & _________
21. No of employees both contract and permanent worker? _________
22. Is your business labor intensive? Yes/no
23. What is your labor cost expenditure from total operational cost in terms of percent? _____
24. Do you use technology to improve productivity/profitability of your business? _________
25. What are the main business activities that generate more solid waste quantity or major solid waste stream points in your business? __________
26. Daily solid waste generation rate? _________
27. Major solid waste consistent in your business? _________
28. How do you remove/discard the solid waste? _________
    a. Burning or burying on-site
    b. Selling for recycler or reuse
    c. Disposing to municipality landfill
29. Do you have solid waste management system? yes/no

ANNEX 4: DATA SHEET FOR DAILY HOUSEHOLD UNIT'S SW GENERATION RATE

No	HH ID	HH kebele & village	Income Class	family size	HH name	Day 1 (kg)	Day 2(kg)	Day 3(kg)	Day 4 (kg)	Day 5 (kg)	Day 6 (kg)	Day 7 (kg)	Total (kg)	Remark
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

ANNEX 5: DATA SHEET FOR DAILY HUSEHOLD UNIT’S SW COMPOSITION

Day	Income class	Paper cardboard	Food waste	Bone	Chat waste	plastic	glass	metal	Textile	leather	Tire & rubber	wood	other	Total
Day 1	Low													
	Middle													
	High													
Day 2	Low													
	Middle													
	High													
Day 3	Low													
	Middle													
	High													
Day 4	Low													
	Middle													
	High													

ANNEX 6: DATA SHEET FOR DAILY NON-HOUSEHOLD UNIT'S SW GENERATION RATE

No	Business category	Non-HH Unit Name	Day 1 (kg)	Day 2(kg)	Day 3(kg)	Day 4 (kg)	Day 5 (kg)	Day 6 (kg)	Day 7 (kg)	Total (kg)	Remark
1	Health Business (HB)										
2	Education Business (EB)										
3	Hotel & Restaurant Business (HRB)										
4	Transport, Utility & Maintenance Business (TUMB)										
5	Public and Privet Office (PPO)										
6	Wholesales & Retailer Business (WSRB)										
7	Agricultural Product Exporter & Importer Business (APEIB)										
8	Manufacturing Industry Business (MIB)										
9	Construction Business (CB)										

ANNEX 7: DATA SHEET FOR DAILY NON-HOUSEHOLD UNIT'S SW COMPOSITION

No	Non-HH unit name	Paper cardboard	Food waste	Bone	Chat waste	plastic	glass	metal	Textile	leather	Tire & rubber	wood	other	Total
1	Health Business (HB)													
2	Education Business (EB)													
3	Hotel & Restaurant Business (HRB)													
4	Transport, Utility & Maintenance Business (TUMB)													
5	Public and Privet Office (PPO)													
6	Wholesales & Retailer Business (WSRB)													
7	Agricultural Product Exporter & Importer Business (APEIB)													
8	Manufacturing Industry Business (MIB)													
9	Construction Business (CB)													

ANNEX 8: SOLVER ANSWERER REPORT

Microsoft Excel 16.0 Answer Report for 100% Coal and % SWM						
Worksheet: [Paper work modified final.xlsx]PAPER (model) (0%)						
Report Created: 2/8/2019 9:11:15 AM						
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.						
Solver Engine						
	Engine: Simplex LP					
	Solution Time: 0.094 Seconds.					
	Iterations: 14 Subproblems: 0					
Solver Options						
	Max Time Unlimited, Iterations Unlimited, Precision 0.000001					
	Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Solve Without Integer Constraints, Assume NonNegative					
Objective Cell (Min)						
	Cell	**Name**	**Original Value**	**Final Value**		
	$G$5	Objective Totals	0.689577446	0.689577446		
Variable Cells						
	Cell	**Name**	**Original Value**	**Final Value**	**Integer**	
	$B$35:$E$35					
	$B$35	Solution COAL	0.125	0.125	Contin	
	$C$35	Solution SWM	0	0	Contin	
	$D$35	Solution LS	1.20432126	1.20432126	Contin	
	$E$35	Solution CLAY	0.334094065	0.334094065	Contin	

Constraints						
	Cell	**Name**	**Cell Value**	**Formula**	**Status**	**Slack**
	$G$10:$G$14 <= $I$10:$I$14					
	$G$10	MgO Totals	3.05	$G$10<=$I$10	Not Binding	0.048049069
	$G$11	K2O Totals	0.76	$G$11<=$I$11	Not Binding	0.23572665
	$G$12	Na2O Totals	0.43	$G$12<=$I$12	Not Binding	0.566195715
	$G$13	SO3 Totals	0.17	$G$13<=$I$13	Not Binding	0.830838265
	$G$14	other HM Totals	0.18	$G$14<=$I$14	Not Binding	0.815137218
	$G$15:$G$20 <= $I$15:$I$20					
	$G$15	AM-UPPER Totals	(0.10)	$G$15<=$I$15	Not Binding	0.098848958
	$G$16	AM-LOWER Totals	(2.33)	$G$16<=$I$16	Not Binding	2.327395669
	$G$17	SM-UPPER Totals	(3.03)	$G$17<=$I$17	Not Binding	3.034102173
	$G$18	SM-LOWER Totals	(2.24)	$G$18<=$I$18	Not Binding	2.244326631
	$G$19	LSF-UPPER Totals	(2.87)	$G$19<=$I$19	Not Binding	2.868523263
	$G$20	LSF-LOWER Totals	(2.67)	$G$20<=$I$20	Not Binding	2.671764351
	$G$21:$G$24 <= $I$21:$I$24					
	$G$21	SiO2 Totals	21.60	$G$21<=$I$21	Not Binding	3.401434422
	$G$22	Al2O3 Totals	5.56	$G$22<=$I$22	Not Binding	10.4376115
	$G$23	Fe2O3 Totals	3.23	$G$23<=$I$23	Not Binding	12.76500716
	$G$24	CaO Totals	65.00	$G$24<=$I$24	Binding	0
	$G$25	NCV Totals	3,138.00	$G$25=$I$25	Binding	0
	$G$26	Mass balance Totals	100.00	$G$26=$I$26	Binding	0
	$G$27	TSR (0%SWM) Totals	-	$G$27<=$I$27	Binding	0
	$G$28	Coal Upper bound Totals	0.13	$G$28<=$I$28	Binding	0
	$G$29	SWM Upper bound Totals	-	$G$29<=$I$29	Not Binding	0.023
	$G$30	Coal lower bound Totals	0.13	$G$30>=$I$30	Not Binding	0.13
	$G$31	SWM lower bound Totals	-	$G$31>=$I$31	Binding	-

Microsoft Excel 16.0 Answer Report for 77% Coal and 13% SWM feed rate						
Worksheet: [Paper work modified final.xlsx]PAPER (model) (13%) 1						
Report Created: 2/8/2019 9:27:55 AM						
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.						
Solver Engine						
	Engine: Simplex LP					
	Solution Time: 0.156 Seconds.					
	Iterations: 18 Subproblems: 0					
Solver Options						
	Max Time Unlimited, Iterations Unlimited, Precision 0.000001					
	Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Solve Without Integer Constraints, Assume NonNegative					
Objective Cell (Min)						
	Cell	**Name**	**Original Value**	**Final Value**		
	$G$5	Objective Totals	0.677089218	0.677089218		
Variable Cells						
	Cell	**Name**	**Original Value**	**Final Value**	**Integer**	
	$B$36:$E$36					
	$B$36	Solution COAL	0.10875	0.10875	Contin	
	$C$36	Solution SWM	0.020952234	0.020952234	Contin	
	$D$36	Solution LS	1.203847461	1.203847461	Contin	
	$E$36	Solution CLAY	0.336763402	0.336763402	Contin	

Constraints						
	Cell	**Name**	**Cell Value**	**Formula**	**Status**	**Slack**
	$G$10:$G$14 <= $I$10:$I$14					
	$G$10	MgO Totals	3.05	$G$10<=$I$10	Not Binding	0.048590441
	$G$11	K2O Totals	0.77	$G$11<=$I$11	Not Binding	0.226223312
	$G$12	Na2O Totals	0.44	$G$12<=$I$12	Not Binding	0.557947263
	$G$13	SO3 Totals	0.16	$G$13<=$I$13	Not Binding	0.837398326
	$G$14	other HM Totals	0.17	$G$14<=$I$14	Not Binding	0.831301602
	$G$15:$G$20 <= $I$15:$I$20					
	$G$15	AM-UPPER Totals	(0.13)	$G$15<=$I$15	Not Binding	0.133952595
	$G$16	AM-LOWER Totals	(2.30)	$G$16<=$I$16	Not Binding	2.297856497
	$G$17	SM-UPPER Totals	(2.97)	$G$17<=$I$17	Not Binding	2.970798268
	$G$18	SM-LOWER Totals	(2.30)	$G$18<=$I$18	Not Binding	2.298810177
	$G$19	LSF-UPPER Totals	(2.91)	$G$19<=$I$19	Not Binding	2.909922249
	$G$20	LSF-LOWER Totals	(2.63)	$G$20<=$I$20	Not Binding	2.633587517
	$G$21:$G$24 <= $I$21:$I$24					
	$G$21	SiO2 Totals	21.65	$G$21<=$I$21	Not Binding	3.351760956
	$G$22	Al2O3 Totals	5.54	$G$22<=$I$22	Not Binding	10.45533141
	$G$23	Fe2O3 Totals	3.24	$G$23<=$I$23	Not Binding	12.75609608
	$G$24	CaO Totals	65.00	$G$24<=$I$24	Binding	0
	$G$25	NCV Totals	3,138.00	$G$25=$I$25	Binding	0
	$G$26	Mass balance Totals	100.00	$G$26=$I$26	Binding	0
	$G$27	TSR (@ 13% of SWM) Totals	407.94	$G$27<=$I$27	Binding	0
	$G$28	Coal Upper bound Totals	0.11	$G$28<=$I$28	Not Binding	0.01625
	$G$29	SWM Upper bound Totals	0.02	$G$29<=$I$29	Not Binding	0.002047766
	$G$30	Coal lower bound Totals	0.11	$G$30>=$I$30	Not Binding	0.11
	$G$31	SWM lower bound Totals	0.02	$G$31>=$I$31	Not Binding	0.02

	$G$6:$G$9 >= $I$6:$I$9					
	$G$6	SiO2 Totals	21.62	$G$6>=$I$6	Not Binding	1.62
	$G$7	Al2O3 Totals	5.54	$G$7>=$I$7	Not Binding	0.54
	$G$8	Fe2O3 Totals	3.24	$G$8>=$I$8	Not Binding	0.24
	$G$9	CaO Totals	65.00	$G$9>=$I$9	Not Binding	10.00

ANNEX 9: MATERIAL TYPES AND WASTE FRACTIONS

Material type	**Analyzed waste fractions**
Food waste	Leftover food, vegetable wastes, fruit peels tea and coffee residue, c.
Bone	Bones from discarded food waste e.g. sheep, cattle bones etc
Biomass	Plant material; woody plant material; wooden Pallet, chipboard, plywood, baskets, weed, grass, leaves, branches, et
Paper and cardboard waste	Magazines and advertisement; newsprint; office paper; books; tissue paper; other paper; cardboard and paperboard; paper and cardboard composites
Plastic waste	*Plastic packaging:* PET; HDPE; PP; PS; expanded PS; resin identification code 7; no polymer resin identification code; plastic foil; metal-plastic laminate; *Non-packaging plastic:* PET; PP; LDPE; no resin identification code
Tyre	
Textile	Trouser, Pants, skirts, socks, shirts, bags, leather shoes, sandals, towels, blankets, carpets, rugs, etc
Metal waste	*Metal packaging:* ferrous; non-ferrous; aluminium foil; *Non– packaging metal:* ferrous; non-ferrous
Glass waste	*Glass packaging:* clear, green, brown; *Non packaging glass:* kitchen and table ware glass; other/special glass

Leather	Sanitary products; textiles, leather and rubber; wood; vacuum cleaner bags; other combustibles
Fine soil, ash	Ceramics; ashes, cat litter; gravel, sand and stone; other non combustibles
Other	Aerosols, Electronic equipment, Medicines and drugs, Detergents, Fluorescent tubes, Paint, Vehicle & Equipment Fluids, Used Oil, Batteries, Remainder/Composite Household Hazardous

ANNEX 10: SWM CHEMICAL FORMULA & ELEMENTAL COMPOSITION

Steps for Waste formula calc	wet weight (kg)	Moisture content (%)	Dry weight (kg)	Ash (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Step 1-Total combustable waste fraction(kg)	172510	103740.38	68769.62	3559.82	32971.57	4283.91	25662.56	2050.66	241.11
step 2- converating MC to H&O (kg)	0	0	0	0	0	11526.71	92213.67	0	0
step -3 revised composition (kg)	172510	-	68769.62	3559.82	32971.57	15810.62	117876.2	2050.66	241.11
step -4 molar composition in kg/mol					12	1	16	14	32.06
step -5 molar composition of the waste kg/mol W-MC					2747.63	15810.62	7367.26	146.48	7.52
step -6 normalise mole ratio in mol (wet base)					365	2102	980	19	1
step -5 molar composition of the waste kg/mol WO-MC					2747.63	4283.91	1603.91	146.48	7.52
step -6 normalise mole ratio in mol (Dry base)					365	570	213	19	1
Atomic weight					12	1	16	14	32.06
Weight contribution of element in Dry base					4380	570	3408	266	32.06
Weight contribution of element in wet base					4380	2102	15680	266	32.06
percentage contribution of element in Dry base					50.60	6.58	39.37	3.07	0.37
percentage contribution of element in wet base					19.50	9.36	69.81	1.18	0.14

ANNEX 11: TYPICAL DATA ON ELEMENTAL, ASH AND MOISTURE CONTENT

waste material	Waste density (kg/m3)	Moisture content (%)	Typical moisture Content(%)	Ash (%)	C (%)	H (%)	O (%)	N (%)	S (%)
Food waste	120–480	50–80	70	2–8	48	6.4	37.6	2.6	0.4
Biomass waste	60–225	30–80	64.9	2–6	47.8	6	38	3.4	0.3
Plastic	30–156	1–4	1.4	6–20	60	7.2	22.8		
Paper/cardboard	30–130	4–10	5.9	6–20	43.5	6	44	0.3	0.2
Bone	720	8	8	28.3	42.1	5.83	15.5	7.52	0.38
Tire/ rubber	90-200	1-4	0.8	8-20	71.9	6.07	1.12	0.2	1.06
Textile	30–100	6–15	10.5	2–4	55	6.6	31.2	4.6	0.2
Leather	90–450	8–12	10	8–20	60	8	11.6	10	0.4

Source: Brunner and Schwarz (1983) and Sajjad & Shaukat (2016)