JIMMA UNIVERSITY

COLLEGE OF PUBLIC HEALTH AND MEDICAL SCIENCES

DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCES & TECHNOLOGY

VALORIZATION OF WASTE: ENERGY AND NUTRIENT RECOVERY FROM SOLID WASTE IN JIMMA TOWN, ETHIOPIA

BY: YOHANNIS FETENE (BSc)

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL HEALTH SCIENCES AND TECHNOLOGY, COLLEGE OF PUBLIC HEALTH AND MEDICAL SCIENCES, JIMMA UNIVERSITY FOR PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE & TECHNOLOGY.

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Jimma, Ethiopia

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By: YOHANNIS FETENE ASSEGU (BSc)

ADVISORS:

1. ABEBE BEYENE (PhD)
2. TAFERE ADDIS (MSc)

September, 2014

Jimma, Ethiopia

Declaration

I, the undersigned, declare that this research paper is my original work and has not been presented for a degree in any other university and that all sources of materials used for the research paper has been duly acknowledged.

Name: YOHANNIS FETENE ASSEGU

Signature: __________________________

Date of submission: ______________________________

This research paper has been submitted for examination with my approval as University advisor:

____

DR. ABEBE BEYENE (PhD, Ass. Prof.) (advisor)

____

Mr. TAFFERE ADDIS (MSc) (advisor)

____

Department Head

Abstract

Solid waste, which is a consequence of day-to-day activity of human kind, needs to be managed properly. Jimma, like other towns in the country, faces problems associated with poorly managed solid waste operation. This poor solid waste management and urban growth are posing a threat on sustainable development, which results in human health problem and environmental pollution. This study deals with evaluating the quantity, composition, energy potential and nutrient value. A cross-sectional study design was used to assess the composition as well as the physical and chemical properties of the residential solid waste. The daily solid waste generation and composition of household solid wastes were determined following standard protocols. Estimates of the energy content were made results using bomb calorimeter and models developed on physical composition and proximate analysis. Physical characterization showed that food, yard, textile, leather, rubber, wood, yard, metal, plastic and paper waste were the constituents of all collected waste samples in the study area, but in varying proportions. Proximate analysis showed household solid waste characteristics as: moisture, volatile matter, fixed carbon, and ash content, being 49.38, 41.21, 6.10, and 3.31%, respectively. The total solid waste generated daily from Jimma town household was estimated to be 77,364.46 kg, and the average per capita generation rate was 0.50 ± 0.08 kg/capita/day. The energy content of household solid waste was estimated to be 17.50 MJ/kg for gross heating value (HHV), and 9.54 MJ/kg for net heating value (LHV). Such difference between HHV and LHV is due to high portion of water content of solid waste. Results from selected models showed higher heating values, but still equivalent with the experimental value of 17.5 MJ/kg and fit the minimum level of 7 MJ/Kg net heating value required for incineration projects. Further analysis showed that biodegradable organic waste constituted 62.75% by weight with an average moisture content of 49.38% and good nutrient contents suggest the applicability of household solid waste stream for implementing composting operations. In conclusion we suggest that the residential solid waste can be used as a valuable resource for recycling in the form of organic fertilizer and energy recovery. As such, an economic benefit can be obtained from this waste while avoiding the cost of treatments and disposal. Further study is required with detail analysis of solid waste to optimize its use for both nutrient and energy recovery.

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Abbreviation

AOAC	Association of Official Analytical Chemist
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BTU	British Thermal Unit
C:N	Carbon Nitrogen Ratio
CIWMB	California Integrated Waste Manangement Board
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
Fo	Percentage of food waste [%]
HHV	Higher Heating Value [MJ/kg]
Km	Kilo Meter
LHV	Lowest Heat Value [MJ/kg]
M	Moisture content, mass fraction decimal
MSW	Municipal Solid Waste
MWhel	Mega Watt hour of electric energy
Pa	Percentage of paper/cardboard [%]
PIC	Products of Incomplete Combustion
Pl	Percentage of plastic [%]
PVC	Polyvinyl chloride
Or	Percentage of organic material (food, yard) [%]
SWM	Solid Waste Management
RDF	Refuse Derived Fuel
TWh	Tone Watt-hour
UNDP	United Nations Development Program
UNEPA	United Nations Environmental Protection Agency
VS	Volatile Solid
W	Moisture content [%]
Wt.	Weight

CHAPTER ONE: INTRODUCTION

1.1. Background

As the world hurtles toward its urban future, the amount of MSW, one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization (Hoornweg and Perinaz, 2012). The World Bank report in 2002 that there were 2.9 billion urban residents who generated about 0.64 kg of MSW per person per day. This report estimates that in 2012 these amounts had increased to about 3 billion residents generating 1.2 kg per person per day (Hoornweg and Perinaz, 2012). For these reason in developed nations, waste management basically starts from source reduction and recycling, landfilling and combustion for energy in modern incineration or gasification systems. In some countries, the organic fraction of the waste is treated by anaerobic digestion to produce biogas for fuel consumption (Suberu et al., 2012). But the problem of waste management is a primordial and present issue in developing countries in Africa, particularly Sub-Saharan. Waste generation in Sub-Saharan Africa is approximately 62 million tons per year. Per capita waste generation is generally low in this region, but spans a wide range, from 0.09 to 3.0 kg per person per day, with an average of 0.65 kg/capita/day (Hoornweg and Perinaz, 2012). Transformation of the existing trends in MSW management is necessary for ensuring sustainable environments and other objectives (Abila and Kantola, 2013).

In developed countries, the daily life of people can generate greater quantity of solid waste than developing countries. However most parts of developed nations are efficient in handling waste when compared to developing countries because of waste to energy technology, give emphasis for waste management in urban planning, focus on product design, institutionally efficient etc. And the capacity of developing countries to collect, process and dispose waste is limited due to inadequate infrastructure, finance, inefficient institutional capacity and structure, and low level of awareness systems (Yimer and Sahu, 2014; (Cheru, 2011). For example, Hoornweg and Perinaz (2012) stated that regions in low-income countries tend to have low collection rates, only 46% of the solid waste generated is estimated to be collected compared to the highest collection efficiency at 98% of high income countries (Hoornweg and Perinaz, 2012). The low collection rate situations introduced numerous discomforts to communities and threaten humans' health through direct contact and contamination of water and soil.

In majority of Sub-Sahara African countries the collected waste is indiscriminately thrown away at landfill sites which can pose great threats to water, soil and air environments as well as human health. Moreover, as the existing dumping sites are filled quickly, finding other new sites becomes more and more difficult. Hence, the cost of disposing solid waste increases. The continuous haphazard disposal of solid waste is accelerating and is linked to poverty, poor governance, poor standards of living, and low level of environmental awareness and inadequate knowledge of environmental management (Suberu et al., 2012). Waste collection, transportation and disposal play a very significant role in any complete waste management practice. Similarly, the current condition of MSW management service in different towns of Ethiopia is also becoming a challenge for municipalities. A controlled solid waste disposal system is practiced in small coverage (Cheru, 2011). That means, small proportions of the urban dwellers are served and a large quantity of solid waste left uncollected.

Among major towns of Ethiopia, Jimma is one of the major town of Ethiopia by which proper provision of solid waste management services is still unsatisfactory and incomplete (Tegegn, 2008). Due to the ever greenness of the city, there are piles of rotting vegetables, fruits, fallen leafs, and other wastes around streets, riverbanks, market areas, and open lots. The practice of chewing khat is familiar in Jimma town, its by-product the so-called "Garaba" also contribute waste quantity of the city. The study done in Jimma town indicated that 54% of wastes are organic in nature (Getahun et al., 2012), that arises primarily from the preparation of food for human consumption.

According to Tegegn (2008), in Jimma town illegal dumping of waste on open space, drainage lines, street sides and, besides individual houses and market areas is considered as routine task of residents. Study reveals that the municipal solid waste generated by the population of Jimma town not properly collected and indiscriminately thrown away at the various dumping site on the periphery of urban centers, in ditches, riverbank and in the residential and market area, or at a number of so-called temporary sites. According to the data for 2012 households took the lion share of solid waste generated in the city (Getahun et al., 2012). From the total solid waste generated in the town, household took 87%, street 0.1%, institutions and commercial centers 13% (Getahun et al., 2012). Besides, solid waste collection and disposing practices the number, distribution and sitting of waste storage containers are also another problems of solid waste management of Jimma town. The containers are so few and unevenly distributed, irrespective of the density and optimum travel distance of the beneficiaries. Therefore, peoples throw waste at the vicinity of the city. And also due to containers pickup time not consistent and frequent it became the center of disposal and collection of animals like goat, cat, dog, vulture etc. These spoils the beauty of the town and it affects the health of the inhabitants and poor environmental quality of town depriving citizens a good quality of life as it affects their health and consequently, affect productivity and economic development adversely (Tegegn, 2008).

The efforts made by the municipality of Jimma town to change the situation in the town are also insufficient as it compared to the extent of the problem. Therefore, in order to reduce this situation and achieve efficient solid waste management system of the town, alternative ways of solid waste management service are required. Power generation from solid waste is one of the stringent measures adopted by international communities to prevent escalation of harsh environmental conditions (Suberu et al., 2012). Application of bio-waste resources for electricity and thermal heat has positive mitigation impact on atmospheric pollutions. On the other hand, overdependence on fossil fuels combustion for energy raised serious concerns about the health of living organisms and their immediate environment (Suberu et al., 2012).

Conversion of biomass to energy to replace traditional fuel and use of the biogas slurry as a fertilizer is the current focus of the national biogas program of Ethiopia. Therefore, the significance of using solid waste as a substrate for energy production is doubly laden that means it is a win-win approach (waste to energy) of utilizing it. For instance, gasification/pyrolysis has the tendency to reduce the mass of the waste by 70-80% and volume 80-90% while preserving the land area for waste land filing (Suberu et al., 2012).

1.2. Statements of the problems

Solid waste is inextricably linked to urbanization and economic development. Duly the volume of waste generated in the world today is enormous (Hoornweg and Perinaz 2012). As of 2011, the world generated an estimated two billion tons of MSW, and this number is expected to grow much higher (Amoo and Fagbenle, 2013). The actual per capita rates, however, are highly variable, as there are considerable differences in waste generation rates across countries, between cities, and even within cities (Hoornweg and Perinaz 2012).

Despite progress in solid waste management practices in the decade fundamental institutional, financial, social, and environmental problems still exist. It is determined by the variation in waste quantity and composition, which are due to difference in consumption pattern, recycling/reuse at source, the standard of living, and culture in the city (Ramesha and Diganta, 2012). Conventional waste management focuses largely on waste collection and disposal (landfills). Only limited attempts are made to adopt integrated waste management practices that involve waste reduction at the source, resource recovery and recycling (Gupte and Saptarshi, 2012). As a consequence of these practices, many cities in developing countries are facing environmental and health risks as well as losing economic opportunities in terms of the resource value of the waste. From a sustainable development perspective, the focus is on reduction of waste, followed by recycling, both of which are advantageous in terms of reducing waste volume and GHGs emissions. Several analysis done using the USEPA models show that waste to energy avoids 36 million tons of greenhouse gases yearly. However, not all wastes are recyclable, and as such, an energy recovery method becomes essential (Amoo and Fagbenle, 2013).

In most cities and towns of developing world like Ethiopia, inappropriate handling and disposal of MSW is the most visible cause of environmental degradation, such as air pollution, soil contamination, surface and groundwater pollution, etc (Amare, 2010). Similar development characterizes Jimma city which is a challenge in constructing operational and sustainable solid waste management systems (Filaba, 2008).

Jimma, the largest city in southwestern Ethiopia lacks waste treatment systems. Its solid waste management is poor. This is due to no source separation or sorting, the organization of operations and management structure, collection and disposal systems are poorly organized. And also in the town there is no properly engineered and structured landfilling site, energy recovery and composting are not practiced as alternatives for waste recovery. For this reason there is high risk to human health, and pollution of the environment (air, soil and water) is evident. According to Getahun et al. (2011) open dumping was the major disposal techniques for 35% of residents of the city where as 22% of the city residents were using open burning on any vacant space they found. This implies that the municipal service only collects 25% of the waste generated. It is also important to note that about 54% of the solid waste generated in Jimma town is biodegradable. It means that, if appropriately employed, waste recycling options through composting would help to significantly reduce the waste management burden of Jimma town. But to implement such options nutrient value of the waste should be determined.

Few papers have discussed the trends of MSW management in Jimma town. For example, Faris (1999) discussed the various practices and awareness of solid waste management. Tegegn (2008) studied the household solid waste generation rate and physical composition analysis. Getahun et al (2012) conducted MSW generation current practices and relation to socioeconomic factors. While these studies have mainly focused on MSW quantity, generation rate and management practices in Jimma city. But its full waste composition and characteristics analysis, suitability for power generation has not yet been addressed.

Widespread method in the world for disposal of MSW is landfilling, eventhough it has capability to control the wastes. However the method has several disadvantages, such as hazardous gas emissions and leachate production. For these reasons, it is necessary to consider alternative MSW management strategies like recovery of energy and composting. Yhdego (1993) has reported that composting reduces the volume of waste send to a landfill, up to 50 - 60%. And study conducted by Getahun et al. (2011) examined the effect of different turning frequencies in composting biodegradable municipal solid waste and concluded that composting of municipal solid waste can be the best strategy to manage solid waste and boost agricultural productivity.

On the other hand, a limited supply of natural resources combined with an ever growing demand for energy and raw materials has promoted the development of recovering latent energy resources from municipal solid waste (Amin, 2011). Study conducted by Rao et al. (2010) indicated that the potential energy that could be produced from solid waste in India tops 905 kcal/kg (Rao et al., 2010).

Therefore, it would be of interest to study valorization of biomass for energy and nutrient recovery of waste treatment to decrease the burden on the environment. Recently Gebrehiwot (2011) studied the potential of biogas production using organic MSW. But this study focuses on biogas (methane) estimation and their properties such as total solid, volatile solid and moisture contents. In order to predict the potential use of solid waste as a source of energy, the most relevant parameter to consider is the LHV, because it represents the energy actually available to be converted into heat and/ or electricity (Gagliardi, 1982).

The base of successful planning for a solid waste management system is obtaining reliable information about the generation rate, physical and chemical characteristics, nutrient value of waste being generated. These obtained information determines the decisions for appropriate management system. It is thus a prerequisite for solid waste program mangers to have detail information about the solid waste to set appropriate management system or plan.

Thus, this research was conducted to characterize the different categories of household solid waste, predict the energy potential and nutrient value of household solid waste. The result will have paramount importance in providing relevant information basic to design appropriate solid waste management system in the town of Jimma.

1.3. Significance of the study

This study could give clue about valorization particularly energy and nutrient recovery. This laboratory based study could also initiate developments and implementation of eco-friendly managements of solid waste. Further, the data can be used as a baseline for future investigation

CHAPTER TWO: LITRATURE REVIEW

2.1. Municipal Solid Waste (Source and Components)

Solid wastes can be defined as all wastes in solid form which are discarded as useless or unwanted and in general arise from human activities (Peavy et al., 1985). According to Kazimbaya and Mwale (2001), solid wastes could be also defined as non-liquid and non-gaseous products of human activities, regarded as being useless (Babayemi and Dauda, 2009). The primary source of solid waste is the production of commodities and byproducts from solid materials. The natural cycle of plant growth and decay is a secondary source of solid waste, which is responsible for the portion of the waste stream referred to as yard waste or vegetative waste (Liu and Liptak, 1997).

In terms of generation sites, the principal sources of municipal solid waste are homes, businesses, and institutions (Tegegn, 2008). In developing countries, MSW also contains various amounts of industrial wastes from small scale industries (Cheru, 2011). The majority of substances composing it in developing countries include paper, kitchen waste, plastics, metals, textiles, rubber, and glass (Getahun et al., 2011).

The most important parameter in solid waste management is the quantity to be managed. The quantity determines the size and number of the facilities and equipment required to manage the waste. Also important, the fee collected for each unit quantity of waste delivered to the facility (the tipping fee) is based on the projected cost of operating a facility divided by the quantity of waste the facility receives (Peavy et al., 1985).

The quantity of solid waste can be expressed in units of volume (typically cubic yards or cubic meters) or in units of weight (kg, metric tons). The advantage of measuring quantity in terms of weight rather than volume is that weight is fairly constant for a given set of discarded objects, whereas volume is highly variable (Bailie et al., 1999). For this study both weight and volume units are used to measure the quantity of the waste being generated.

Municipal solid waste management is the generation, separation, collection, transfer, transportation and disposal of waste in a way that takes in to account public health, economics, conservation, aesthetics, and the environment, and is responsive to public demands (Khan et al., 2012; Tegegn, 2008). According to the Tegegn (2008), overall goal of solid waste management should be to collect, treat and dispose of solid wastes generated by all population groups in an environmentally and socially satisfactory manner using the most economical means available. There is a need for a complete rethinking of "waste" to analyze if waste is waste. A thinking that calls for waste to become wealth, refuse become resource, trash to become cash (Tegegn, 2008). Managing solid waste is one of the most essential services which often fail due to rapid urbanization along with drastic increase of the waste quantity and variety of the waste composition. Waste management systems which may be successful at one place are difficult to accept for other places due to waste quantity and composition which vary from country to country.

In Ethiopia city councils and municipalities have insufficient means to solve the problems of solid waste management. There is no clear cost recovery structure related to solid waste management in Ethiopia, hence, there is an extremely low level of returns for efforts put into dealing with solid waste. The solid waste management institutions not only lack funds, but their capacity to work in partnership with the local communities is also limited (Amare, 2010).

According to Ethiopian Environmental Review, since the year 2001, most municipalities and city councils in Ethiopia have become aware of the negative consequences of poor solid waste management and have devised and implemented a system to collect and dispose of solid waste that involves waste collection associations (Amare, 2010). A study conducted in 2004 by UNDP in Bahir Dar, Mekele, Adama, and Hawassa showed that their municipalities collected and disposed of 46, 48, 54, and 50 percent of the solid waste generated daily, respectively (Amare, 2010), (UNDP, 2004).

2.2. Existing Solid Waste Management System in Jimma Town

One of the most important problems of Jimma town is the solid waste management. The problem extends up to the pollution of the environment, especially water bodies, living areas, street and ditches. The pollution increases the health risks of the population and reduces the value of the environment. The city has increasing solid waste generation. Currently, the daily waste generation of the city is 88,000 kg and the per capita daily generation of municipal solid waste is 0.55kg/cap/day (Getahun et al., 2012). The amount of solid waste produced in the residential areas consists of mainly organic materials (54%) such as food, paper of all type, textile, yard waste etc (Getahun et al., 2012). The implication is serious due to rapid urbanization and rapid population growth and the wastes are not efficiently managed. The major accelerators of Jimma city urbanization is the growth of institutions of learning particularly Jimma University, natural increase of population, rural-urban migration, and government policies of infrastructural development, inputs of nongovernmental organizations, marketing and transportation, of all sorts that generate both domestic and commercial wastes.

Jimma due to its transportation center and junction point to other most towns of the western part of the country and evergreen city in south western part of the country, the economic activity is strong and serves large population that generates large volume of waste. Khat chewing is popularly known and widely practiced in the town, which produces large amount of waste and thus increasing the amount of waste generated in the town. According to Mossie (2000) study the prevalence of khat chewer in Jimma town is 30.6% and among khat chewers, 57.8% were regular daily khat chewers (Mossie, 2000).

Walking in the town of Jimma from any corner all public spaces like road sides and open spaces attest eye catching piles of garbage, the use and discarding of plastic bags, commonly called ‘’festal’’ and fallen plant leafs, vegetation leftover and khat by product commonly called "garaba" are observed everywhere in the town and the trend seems to be increasing. The relationship between public health and importance of the more obvious way in which aesthetic are abused in the drooping of litters in towns. Improper management of solid waste could well be major factor contributing to litter problem, which regarding as a measure of citizens pride in his/ her surroundings (Tegegn, 2008).

But very recently, one small scale micro enterprise called “Abdi Jimma community based waste management composting MSE" has started the preparation of compost in the area known as "Becho bore". The enterprise is trying to change organic matter into compost and sell the compost to those who want to use it as a fertilizer. They started the preparation of compost very recently and it aims at creating the awareness for the urban population of the fact that wastes are useful and a means of income.

On the other hand, the role of the informal activity is a good means in reducing the cost of solid waste collection and disposal service. For example, no one has appreciated the so-called "Koraliew" (those individuals who buy empty glasses, metals, tins, old shoes etc) in a door-to-door service. These people, apart from collecting usable materials from homes, they visit containers and disposal sites to gather different materials that they need. Therefore, since this activity reduces the quantity of solid waste that would have been collected by the government, their role in the management of solid waste collection and disposal should be considered as an important informal means of waste management.

Town municipality carries out solid waste management in Jimma town (Abebe and Kebede, 1999). According to city municipality the solid waste management program is under the department of sanitation, beautification and abattoir service. Two tipper lorry for waste collection purpose and 54 metallic containers with a capacity of eight cubic meters are available for waste storage. There are one private sector called "Abamilki" involved in solid waste collection to help the department in this activity and around thirteen micro scale enterprises involved in small-scale solid waste collection, transported the waste to the dumpsite. The collection system in the city is currently based on the application of communal municipality waste containers and door-to-door collection by the micro scale enterprises. Communal waste collection is performed by means of containers placed randomly in overcrowded residential and commercial areas (Getahun et al., 2012). It has showed that collection is undertaken for small portion of the town, it is arbitrary, neither following a definite program basis nor prescribed routes (Abebe and Kebede, 1999). As a result of this, the willingness of the population to cooperate with waste collection operation and to pay for the service is low.

The existing 54 containers cannot serve the entire population of the city because it is believed that waste is daily produced in each and every household (Asrat, 2006). Another problem that is a challenge for solid waste management system in the city is the placing of containers. Containers in each kebele are not evenly distributed. In addition, the filthy and shanty areas where the containers have been placed have affected the public health and the beauty of the city and aggravated the improper use of containers by the residents because the stinky smell of the waste has forced the beneficiaries not to reach the containers and dispose the waste that they have brought from their home near the containers.

Municipal Solid Waste management in Jimma town starts with collection by vehicles with a loading capacity of eight cubic meters. Next stage is transportation to the existing dumping sites which is not properly engineered and managed, pollutant that are released from the disposal sites eventually causing direct and indirect impact to human's life. The disposal site that is currently in use for the total of Jimma town is open field located at a distance of about 5 km from the town on Seka road the so-called kofe. This is an agricultural area where no extra preparation done to make it proper disposal site (Tegegn, 2008).

2.3. Effects and Impacts of Municipal Solid Waste

Municipal solid waste is abundant, unsightly, and potentially odorous; contains numerous potential pollutants; and supports both disease-causing organisms and disease-carrying organisms. Because of these characteristics of municipal solid waste a prompt, effective, and reliable system is required to isolate solid waste from people and the environment (Liu and Liptak, 1997).

If there are no proper management of solid wastes it has many negative impacts that may result. A good understanding about the effects and risks that may arise from improperly managed solid wastes should have given more emphasis for the management work. Tegegn (2008) lists the following as the most important effects associated with uncontrolled solid wastes.

- Uncollected wastes cause blockage of drains, which result in flooding and unsanitary conditions,
- Flies and Mosquitoes breed in some constituents of solid wastes, and flies are very effective vectors that spread disease,
- Waste dumps are good shelter for rats. Rats consume and spoil food, spread disease, damage electrical cables and other materials,
- Uncollected wastes degrade the urban environment, discouraging efforts to keep the streets and open places in a clean and attractive conditions,
- Dangerous items (such as broken glass, razor blades, needles and other healthcare wastes, aerosol cans and potentially explosive containers) may pose risks of injury or poisoning, particularly to children and people who sort through waste,
- Waste items that are recycled without being cleaned effectively or sterilized can transmit infection to later users,
- Polluted water (leachate) flowing from waste dumps and disposal sites can cause serious pollution of water supplies.

- Waste that is treated or disposed of in unsatisfactory ways can cause a severe aesthetic nuisance in terms of smell and appearance.
- Fires on disposal sites can cause major air pollution, causing illness and reducing visibility, making disposal sites dangerously unstable, causing explosions of cans, and possibly spreading to adjacent property and etc.

Infestation of vermin and insects that often serve as potential reservoirs of disease are related to public health. The practice of throwing wastes into unpaved streets, road ways and vacant land led to the breeding of rats, with their attendant fleas carrying the germs of disease that result in disease outbreak which is due to lack of plan for the management of solid (Tegegn, 2008).

When adequate attention is not given to the maintenance of sanitary conditions which is related to aesthetic consideration there can be the production of odors and unsightly conditions. Ecological impacts, such as water and air pollutions, also have been attributed to improper management of solid wastes. For instance, leachate from dumps and poorly engineered landfills contaminate surface waters and ground waters as it may contain toxic elements (Ogwueleka and Ogwueleka, 2010).

2.4. Source Reduction, Reuse and Recycle of Solid Waste

Source Reduction means decreasing the amount or toxicity of the materials that we thrown away. Effective source reduction promotes the use of products that generate the smallest environmental impacts (USEPA, 2003). It includes:

- Purchasing of long lasting goods
- Seeking products and packaging which are as free of toxics as possible.
- Redesigning products to use fewer raw materials in production, have a longer life, or are used again after its original use.

Reusing items- by repairing them, donating them to charity and community groups, or selling them are recommended by international communities to reduce waste. Reusing products, when possible, is even better than recycling because the item does not need to be reprocessed before it can be used again. Whereas, recycling turns materials that would otherwise become waste into valuable resources. In addition, it generates a host of environmental, financial, and social benefits. Materials like glass, metal, plastics, and paper are collected, separated and sent to facilities that can process them into new materials or products (Bailie et al., 1999; Tegegn, 2008).

Waste reduction is distinguished from recycling, which reduces the quantity of waste requiring disposal but does not reduce the quantity of material to be managed. Based on the composition of MSW each of the following measures would have a significant impact on the quantity of MSW entering the solid waste management system according to (Peavy et al., 1985):

- Leaving grass clippings on the lawn
- Increasing backyard composting and mulching of leaves and other yard wastes
- Selling products in bulk rather than in packages, with the consumer providing the containers
- Buying no more food than is eaten
- Substituting reusable glass containers for paper, plastic, and single-use glass containers
- Reusing shopping bags
- Placing refuse directly in refuse containers instead of using trash bags
- Using sponges and cloth hand towels in place of paper towels
- Continuing to use clothing and other products until they are worn out, rather than discarding them when they no longer look new
- Prohibiting distribution of unsolicited printed advertising

Almost all solid waste materials can be recycled in some way if people are willing to devote enough time and money to the recycling effort. Because time and money are always limited, distinctions must be drawn between materials that are more and less difficult to recycle. Some recyclable material becomes unmarketable through contamination during use. A significant fraction of recyclable material cannot be recovered from the consumer. According to Teka (2006) in Addis Ababa 10% of the total solid waste generated is composted and recycled. Very little is done at the waste generating sources and community levels to reduce the volumes of waste through efficient sorting, recycling and composting activities. Most of the sorting and recycling of waste at the moment is done by the informal sector (Teka, 2006).

A portion of both recyclable and compostable material is lost during processing (sorting recyclable materials or removing non recyclable and non compostable materials from the waste stream). Some compostable material does not decompose enough to be included in the finished compost product and is discarded with the process residue (Tchnobanoglous et al., 1993).

Practically, microbes like bacteria; fungi etc break down the organic matter found in the waste to produce CO_2, water, heat and a stable and nutrient-rich organic product useable for soil amendment (Becidan, 2007). Many parameters are of importance to optimize the composting process such as: C/N ratio, particle size/surface area exposed (the smaller the particle, the easier for micro organisms to work), oxygen/aeration, moisture content, pH level, temperature (Becidan, 2007). For the vast amount waste to be composted traditional windrow system and large incubator in-vessel systems are exist as technical solutions. To ensure fast, efficient and safe decomposition, recommends "active (or fast, hot) composting" operation is preferred to passive composting where no maintenance is applied. Active composting requires the follow-up and optimization of aeration, moisture and C/N ratio throughout the composting matter (Baum and Parker, 1973).

2.5. Energy Potential of Solid Waste

The amount of energy production from the combustion of solid waste provides only a small proportion of today's soaring power demands, but it is not negligible. There is a call for to supply energy from other resources due to some fuel are approaching depletion (Ucuncu & Vesilind, 2006). Amanuel (2011) in his study stated that the benefits of energy recovery from municipal solid wastes are largely unquestionable, both for the energy benefits itself and for the positive environmental implications, mainly related to the saving of primary energy derived from fossil fuel. However the waste-to-energy options can be several, leading to different strategies based on the conversion plant itself and on the possible inclusion of waste pre-treatment units (Amanuel, 2011).

The annual Swedish biogas production is around 1.3 TWh. Agriculture represents the greatest potential resource to increase production of biogas in Sweden. This is especially the case for cultivated crops, but also for waste products such as manure and more food waste could also be used to produce biogas. The theoretical potential biogas production in Sweden has been estimated to 14 TWh/year that is ten times greater than the current value (Linne and Bryant, 2004)

The annual production of municipal solid waste in Russia accounts for 35 million tons, 337 kg per capita while around 40% of MSW consists of easily biodegradable food residues or bio-waste. Annual generation of these in Russia accounts for 14 million tons (50% dry mass). Under anaerobic digestion of bio-waste, one can obtain 2.1 billion m3 of biogas (70% methane, biogas yield: 0.3 m3/kg Dry matter) and 2.3 million tons of high quality organo-mineral fertilizers (Kalyuzhnyi, 2008).

In 2005, 42 million tons of MSW were landfilled in California, about 64% (by weight) of which is of biological origin (CIWMB, 2007). To reduce the amount of waste destined for landfills, the organics from MSW can be separated and treated through conversion technologies for volume reduction and generation of valuable by products, such as biogas energy and compost. The increasing energy prices make the anaerobic digestion appear to be a more attractive process for achieving both waste reduction and energy recovery.

Africa is a continent with abundant, diverse and unexploited renewable energy resources that are yet to be used for improving the livelihood of the vast majority of population (Mshandete & Parawira, 2009). The same study explain that the production of biogas via anaerobic digestion of large quantity of agricultural residues, MSW and industrial waste would benefit African society by providing a clean fuel from renewable feedstock and help end energy poverty. There is a consensus that achieving the millennium development goals in Africa will require a significant expansion of access to modern and alternative renewable energy (Mshandete and Parawira, 2009).

According to assessment on potential for agro-industrial biogas in Kenya, the total potential installed electric capacity of all sub-sectors MSW, sisel production, coffee production) ranges from 29 to131 MWhel, generating 202 to 1045 GWhel, which is about 3.2 to 16.4% of the total Kenyan electricity production of 6360 GWhel as of 2007/2008 (Agro-Industrial-Biogas-in-Kenya, 2010).

Julius (2005) study, in Ghana, non-conventional energy exploitation through useful harnessing of biomass energy locked up in urban solid waste into grid energy seems to be a more likely option that has won both political and public debates on alternative energy sources. This option seems to have found both public and political favor because of its potential dual ability to abate environmental pollution problems through solid waste reduction and its capability to generate substantial thermal energy through waste-to-energy conversion by incineration in mass burn or refuse-derived fuel (Julius, 2005).

(Tay, 1988) discussed waste heat recovered from the boilers can be used to generate electricity: 155 KWh of electricity could be generated for every tone of refuse incinerated. The revenue collected from the electricity and scrap iron recovered from the incineration plant could offset the annual operating cost of the plant.

Fruergaard et al. (2010) stated that MSW incineration contributes with 20% of the heat supplied to the more than 400 district heating networks in Denmark. In evaluation of the environmental consequences of this heat production, the typical approach has been to assume that other (fossil) fuels could be saved on a 1:1 basis. He also investigates the consequences of waste-based heat substitution in two specific Danish district heating networks and the energy-associated interactions between the plants connected to these networks. Despite almost equal electricity and heat efficiencies at the waste incinerators connected to the two district heating networks, the energy and CO_2 accounts showed significantly different results: waste incineration in one network caused a CO_2 saving of 48 kg CO_2/GJ energy input while in the other network a load of 43 kg CO/GJ.

According to the study by Amanuel (2011), the potential electricity that can be generated by incineration from 22149497.13kg/year masses of wastes around 2.6MW of electricity could be generated. This is equivalent to annual saving of 18,049,681birr where the electricity selling price were 0.29 birr/KWh. And if such waste were landfilled with a valid assumption is made the potential landfill gas that could be obtained was calculated as 120270.05 m^3/year. Taking this value as the annual potential landfill gas generation, he conclude that the electricity production potential was around 548,063.94 KWh (Amanuel, 2011).

Gagliardi (1982) has studied the incineration of mixed paper waste with heat recovery and examined the three alternatives of heating alone, both heating and cooling, and heating, electric generation and cooling together. He believes that the economic analysis is more favorable for larger systems. He also concludes that paper waste incineration is a disposal method in which everybody benefits.

Giugliano et al. (2008) compared the process of gasification developed by TPS Termiska, the process of Battelle gasification, the traditional combustion of MSW in a dedicated grate combustor and the combustion of RDF in a dedicated grate combustor. He concluded that gasification shows the best electrical conversion efficiency but has higher operating costs which outweigh the lower capital costs, thus leading to higher total costs (Giugliano et al., 2008).

2.6. Parameters Affecting Energy Recovery

The main parameters which determine the potential of recovery of energy from wastes (including MSW) (Das and Hoque, 2014; Charles et al., 1995) are:

- Quantity of waste, and
- Physical and chemical characteristics (quality) of the waste.

The actual production of energy will depend upon specific treatment process employed. The important physical parameters requiring consideration include:

- Size of constituents
- Density
- Volume

Smaller size of the constituents aids in faster decomposition of the waste. Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions (Amanuel, 2011).

The important chemical parameters to be considered for determining the energy recovery potential and the suitability of waste treatment through bio-chemical or thermo-chemical conversion technologies include: -

- Volatile Solids
- Fixed Carbon content

- Moisture content
- Calorific Value
- C/N ratio (Carbon/Nitrogen ratio)

Based on the study of Amin (2011) determination of the heating value of municipal solid waste samples can be done either experimentally or by using mathematical models. Experimental determination by using a bomb calorimeter utilize a sample size of one gram which is inadequate to account for the vast variance in municipal solid waste composition, thus requiring bigger sample size. Furthermore, he explained the experimental method is tedious and also requires technical skills in handling the equipment and the combustion by products. As for the mathematical models, they were created to avoid over reliance on lengthy experimental techniques (Amin, 2011).

Recently, Julius, (2005) studied the potential of municipal solid wastes for utilization in energy production in Accra, Ghana, using bomb calorimeter to predict calorific content. And also Ojolo et al. (2008) studied the potential of biogas production using MSW in Nigeria. This study focuses on prediction of lower heating value of municipal solid waste in Nigeria. The same author explained that, in order to predict the potential use of municipal solid waste as a fuel, the most relevant parameter to consider is the LHV (Ojolo et al., 2008; Ogwueleka and Ogwueleka, 2010).

The Lowest Heating Value is defined as the energy content released from the combustion of the organic component of MSW in an incinerator and can be used to represent the energy content of MSW. The energy content of MSW can be determined by: using a full scale boiler as a calorimeter, a laboratory bomb calorimeter, and calculation based on empirical models (Ogwueleka and Ogwueleka, 2010).

However, the components of the wastes vary increasingly with the life style and economic standards of the population. It is therefore necessary to know the exact composition of wastes under study. According to Charles et al. (1995) the basic component materials in the citywide waste stream can be classified as: food waste; yard waste; paper waste; plastics waste; textile waste; rubber and leather waster; glass and ceramic waste; wood waste; metals and miscellaneous wastes.

Regarding the empirical approaches, there are three types of models that are used to predict calorific values based on the following analyses :

I. Physical composition
II. Ultimate analysis
III. Proximate analysis

Determination of the energy content of the MSW is not an easy task. This is because of the equipment limitation and the complex nature of the wastes. Also, MSW composition varies amongst communities and even within one community from year to year, but the differences is not substantial.

In this study, amount of calorific value determined by using both experimental bomb calorimeter and mathematical models based on (Abu-Qudais and Abu-Qdais, 2000; Kathiravale et al., 2003) and (Uson et al., 2012) but due to equipment (Elemental Analyzer) limitation experimental ultimate analysis has not been performed.

Table 1: The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes (Amanuel, 2011).

Waste Treatment Method	**Basic principle**	**Important Waste Parameters**	**Desirable Range**
Thermo-chemical Conversion • Incineration • Pyrolysis • Gasification	Decomposition of Organic Matter by Action of heat	Moisture content	< 45 %
		Volatile matter	> 40 %
		Fixed Carbon	< 15%
		Total Inserts	< 35%
		Calorific Value	> 1200 kcal/Kg
Bio-chemical conversion Anaerobic Digestion/Bio-methanation	Decomposition of Organic Matter by Microbial Action	Moisture content	> 50 %
		Volatile matter	> 40 %
		C/N	25-30

Conceptual Framework

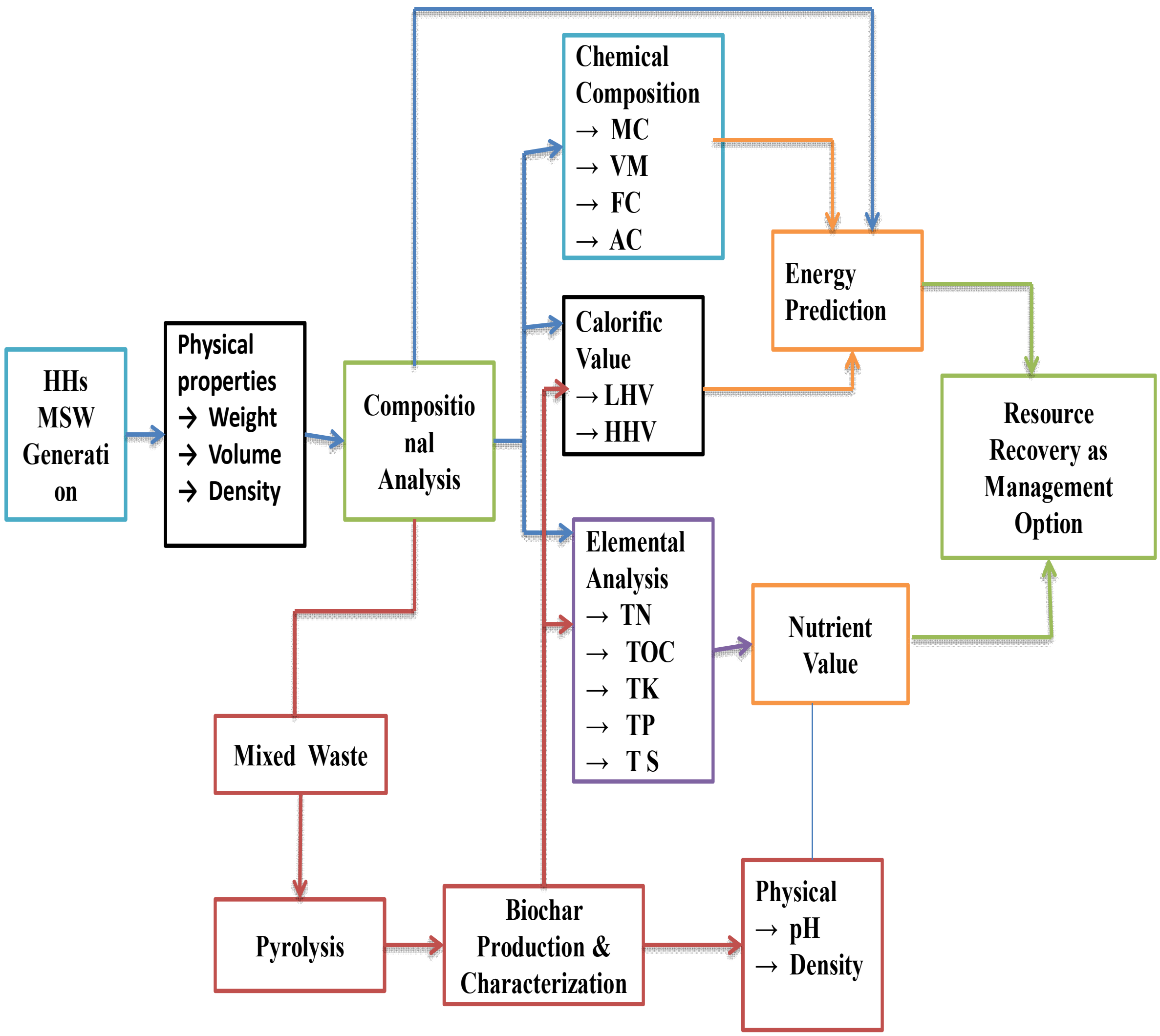


Figure 1. Conceptual Framework

CHAPTER THREE: OBJECTIVE

2.1. General objective

The objective of this study was to predict the energy potential and nutrient values from solid waste of Jimma town.

2.2. Specific Objectives

1. To investigate the physicochemical characteristics of different solid waste components
2. To examine potential energy content of solid waste components
3. To compare the reliability of models in predicting the energy recovery potentials from different solid waste components
4. To evaluate the potential of using solid waste for energy recovery byproducts as organic fertilizer or soil amendment

CHAPTER FOUR: METHODS AND MATERIALS

4.1. Study Area

This study was conducted at Jimma town. Jimma is one of the cultural and historical towns in the southern part of Ethiopia, which has been founded the late 1830s, is locally known as the town of Aba Jiffar. Since then it has been the center of most of the regimes administration and commercial activities. It is situated 346 kms from Addis Ababa on the high way of Mettu - Gambella and Teppi - Mizzan.

The town has a total area of 46.23 square kilometers and is divided into 13 kebeles. The number of households reported in the town are 27,757 with total population of 155,436 of them 77,267 (49.7%) are females and 78,169 (50.3%) are males (CSA, 2013). Geographically the town lies between 7° 40' 42" latitude North and 36° 49' 24" longitude East. It is found in an area of average altitude, of about 5400 ft (1780 m) above sea level. It lies in the climatic zone locally known as Woyna Dega which is considered ideal for agriculture as well as human settlement. From a climatic point of view, abundant rainfall makes this region one of the best watered of Ethiopian part, conducive for agricultural production (Seifu, 2002).

Prior to the detailed data collection, preliminary field visit was made to major parts of the town including residences and discussions were held with concerned officials and some residents for preliminary investigation and assessment of the existing solid waste management system in reference to the different functional elements. This includes the activities such as waste handling at the source, collection, transportation, resource recovery mechanisms and disposal in the town.

Four kebeles which were considered in this study are Ginjo, Mendera Kochi, Becho Bore and Hermata Mentina kebeles which were expected to represent all kebeles.

4.2. Study Design and Period

A cross-sectional study conducted from March to April/2014 to assess the physical and chemical properties of the residential solid waste of Jimma town to predict the energy potential and nutrient values.

4.3. Sample Size Determination

To determine sample size of households participating in the study, a sample size determination formula developed by Cochran (1977) was used. Mathematical presentation of the formula is given by Eq. (1)

$$n = \frac{z^2 * (p) * (1 - p)}{c^2} \quad (1)$$

Where:

n is sample Size (number of sample to be sorted)

Z is Z-value (95% confidence Interval = 1.96)

p is percentage of waste produced by households

c is confidence interval expressed by decimal (0.056)

According to data obtained from Getahun et al. (2012) the total solid waste generated in Jimma town, about 87% (P) of the waste are generated from households, the rest 13% from institutions, commercial centers, and street. Then the calculated sample size given as:

$$n = \frac{1.96^2 * (0.87) * (1 - 0.87)}{0.056^2} = 137$$

n = 137 was the minimum sample size of housing units for reliable results

4.4. Sampling Technique and Procedure

Jimma town has 27,757 housing unit. These households are stratified in to thirteen kebeles by city administration. Because of the households in the towns are homogenous in living standards in all kebeles, four kebeles were selected by simple random sampling technique using SPSS version 16 random selection, which was applied for all kebeles to gave equal chance to be selected. The required sample size was calculated using a standard formula (Cochran, 1977), resulting in a calculated total sample size of 137 households. Then, the sample size of 137 determined above were allocated for the four selected study kebele households based on population proportion: n_1= 41, n_2 = 34, n_3 = 43 and n_4= 19 households from Ginjo, Mendera Kochi, Becho Bore and Hermata Mentina respectively.

Individual households that participated in the study was drawn by systematic random sampling method. The interval used to select the households for waste collection was determined depending on the number of total households as $k_i = N_i/n_i$ for each selected kebeles. The first house was randomly chosen from the selected kebele, and the subsequent units (households) were chosen on the basis of N/n. If the selected housing units were not serving as a housing unit; the next housing number was directly selected. The selected households were informed about the purpose of the study that it was for scientific purpose and to generate baseline data for the solid waste management of the town.

The samples were collected from four kebeles at households of the town. The determination of the mean composition were based on the collection and manual sorting of a number of samples of waste over a selected time period covering one week time period for each samples (Charles et al., 1995; Gidarakos et al., 2005).

4.5. Waste Collection and Sorting Procedure

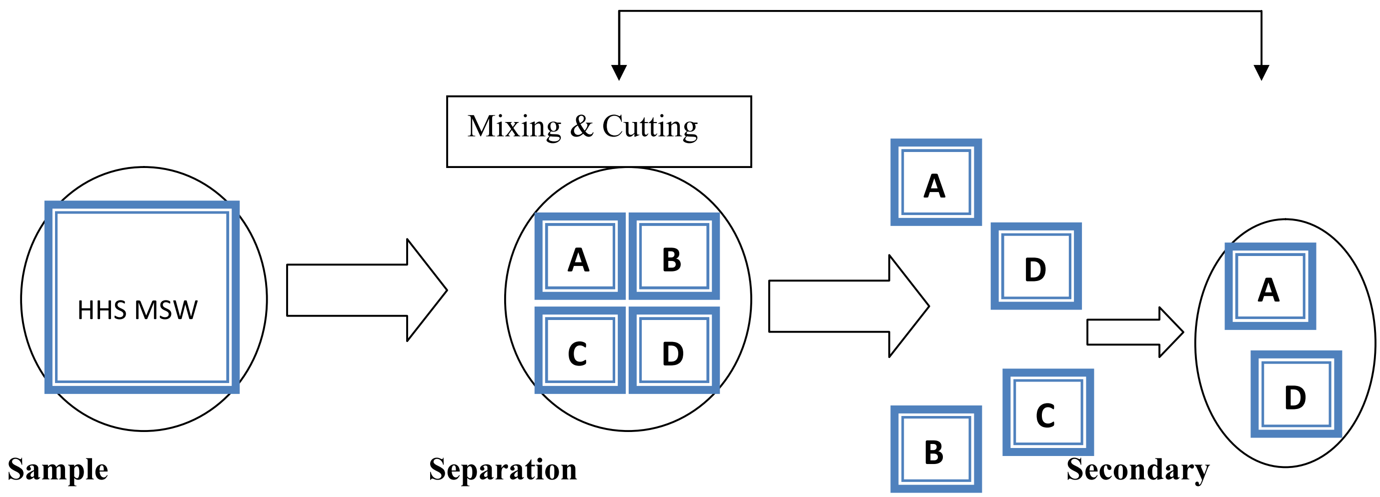
Direct sampling, sorting, weighting and quartering of wastes from the participating households were conducted for eight consecutive days, but the first day data were discarded to be confident enough, assuming that it was composite of waste stored for more than one day’s solid waste generated. In order to have an average result of the whole days of the week, in case of differences in waste generation between days, for each households were given a plastic bag, having the same size, labeled with its house code. Next day during collection, another bag with the same label were given for the next day collection, according to the work plan this process were continued for a week. Wastes collected from the second to the eight days represent one week’s solid waste production. Those plastic bags were collected and transported to the analysis site using a pushcart and horse cart. The waste was collected each morning for sorting and weighting at becho bore. The collected waste was first weighed to obtain the weight of waste for each households. Weighing was carried out three times and an average value was taken. This procedure has been followed throughout the study period.

Waste was sorted into 10 containers by predetermined components. Periodically, during the analysis the 10 plastic containers were weighed and then emptied. The plastic containers were weighed (three times as before) to record the amount of waste sorted in each predetermined categories. Since solid waste density was needed as part of the study, the volume of the waste was measured and recorded at this point just by lift and drop the plastic or wood bucket container five times to allow the waste to settle. Finally 10 plastic containers were emptied into disposal facilities provided and these processes were continued until all wastes analyzed.

Homogenized samples, with appropriate sample taking, handling and transportation mechanism, were taken for proximate analysis to Jimma University Environmental Laboratory and Calorific Value and Elemental analysis to Ethiopian geological survey laboratory and JIJE Analytical Testing Service Laboratory.

4.5.1. Quartering Method

Quartering was evaluated for precision and efficiency in the analysis of household solid waste. These were divided into four sections after cutting large pieces and mixing, and two diagonal sections are again mixed. The procedures are shown in figure below and they are done several times by four men. We repeat the procedures several times until solid waste weight is 10-15 kg.



4.6. Proximate, Calorific Value and Elemental Analysis

Procedures used for analysis are summarized as follows. The laboratory sample consisted of five sub-samples: food waste, yard waste, papers waste, plastics waste and textile waste. The quantity of each fraction was based on the weight percentage composition. The inorganic components including miscellaneous present in the sample (rock, sand, plaster, bones, ashes, paint strippers, paint residues, other organic and inorganic materials, etc.) were removed from laboratory analysis after sorting. Therefore, only the selected organic and combustible fraction of the households' solid waste were analyzed. Based on the above, the results of the analyses of the household solid waste are expressed on a per organic and combustible fraction basis; that is, the results are expressed per household solid waste fraction after the removal of the inorganic components. For the temporary storage and transport of each sample to the laboratory, waterproof plastic bags were used. The time interval between collection and arrival at the laboratory was three hour. For the preparation of laboratory samples, necessary safety equipment like gloves was used. Size reduction of materials was achieved using knives and scissors.

4.6.1. Proximate Analysis

Proximate analysis consists of % moisture content, % ash content, % volatile matter and fixed carbon were determined by putting sampled waste to different range of temperature, between 100 to 950°C. The samples for proximate analysis were taken from each components of the waste by homogenizing the total collected sampled waste components. The laboratory methods to measuring the proximate analysis of samples in this research were conducted according to ASTM cited in (Gidarakos et al., 2005).

4.6.1.1. Moisture Content

The percent moisture content of the household solid waste samples were determined by weighing 1 kg of the samples into a pre weighed dish and drying the samples in an oven at 105°C for one hour and it was repeated until a constant weight reached. The percent moisture content was calculated as a percentage loss in weight before and after drying for each solid waste component. Eq. (2): cited in (Gidarakos et al., 2005).

$$\%\ \text{Moisture content} = \left[\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet weight}}\right] x\ 100 \qquad (2)$$

4.6.1.2. Volatile Matter Content

The volatile matter content was determined by ignition of the sample at 950°C. The triplicate samples of the solid waste components used in the moisture content determination were weighed and placed in a muffle furnace for 7 minutes at 950°C. After combustion, the samples were weighed to determine the ash dry weight, with volatile solids being the difference between the dried solids and the ash, Eq. (3):

$$\% \text{ VS } = \left[\frac{\text{Dry sample weight} - \text{Ash weight}}{\text{Dry sample weight}}\right] x\ 100 \qquad (3)$$

4.6.1.3. Ash and Fixed Carbon Content

Ash content of waste is the non-combustible residue left after waste is burnt, which is represents the natural substances after carbon, oxygen, sulfur and water. Analysis include the dried sample was heated in a ceramic crucible at 750°C for 1 hour. Fixed carbon was defined by carbon found in the ash sample was calculated using the following equation (4):

$$\text{Fixed carbon (Wt\% wet basis)} = 100 - (\text{Wt \% moisture content} + \text{Wt \% Ash} + \text{Wt \% volatile matter}) \qquad (4)$$

4.6.3. Calorific Value

The energy content of the organic and combustible components in households solid waste were determined by experimental bomb calorimeter and mathematical models based on compositional and proximate analysis result. In experimental determination, known dry weights of solid waste samples were grounded and milled in a blender and fed into a bomb calorimeter. The samples were then ignited in excess oxygen at 30 bars using an electric arc where the rise in temperature due to combustion of the sample was noted and the calorific values of the sample read. The analysis were performed in triplicates for each samples.

Several empirical models have been developed to describe and predict the energy content of solid waste (Uson et al., 2012; Amin, 2011; Kathiravale et al., 2003; Abu-Qudais and Abu-Qdais, 2000). Table 2 summarizes some of the published models that correlate the energy content of MSW with its compositional and proximate analysis. Models predict HHV, which assumes that all of the water in the products has condensed to liquid and LHV assumes that none of the water has condensed. HHV scenario liberates the most amount of energy, as condensation is an exothermic reaction; hence values are higher than LHV (Abu-Qudais and Abu-Qdais, 2000). The LHV is a better measure than the HHV of the heat released by the waste under actual operating conditions, however in most instances only HHV is reported. HHV includes the heat of condensation of water vapor formed in the combustion reaction, which is not realistic for industrial combustion equipment, as water in the final combustion products remains as vapor (Cooper et al., 1999). An estimate of the LHV is obtained from the measured HHV by subtracting the heat of vaporization of water in the products, as shown in Eq. (5). Calculation considers wet weight, heating values at constant pressure, the wet basis moisture content in mass fraction decimal, and the latent heat of vaporization of water (Komilis et al., 2012). The difference between HHV and LHV expressed by the following equation:

$$\mathrm{LHV} = \mathrm{HHV}(1 - \mathrm{M}) - 2.443\mathrm{M} \qquad (5)$$

Table 2: Some of the models available from literature review for the prediction of heating value.

Name	Equations	Remark	Units	Reference
Model based on proximate analysis:				
Eq. (7)	356.248VM - 6998.497	Dry (Wt %)	KJ/Kg	Kathiravale, et al (2003)
Eq. (8)	356.047VM - 118.035FC - 5600.613	Dry (Wt %)	KJ/Kg	Kathiravale, et al (2003)
Eq. (9)	44.75VM - 5.85W + 21.2	Wet (Wt %)	Kcal/Kg	Kathiravale, et al (2003)
VM = %Volatile Matter, FC = Fixed Carbon, W = Total Moisture				
Model based on Compositional analysis:				
Eq. (10)	0.004(267(pl/pa) + 2285.7)	Wet (Wt %)	MJ/Kg	Abu-Qudais and Abu-Qdais (2000)
Eq. (11)	0.001(112.15Fo + 183.386Pl + 5064.701)	Wet (Wt %)	MJ/Kg	Kathiravale, et al (2003)
Eq. (12)	0.001(112.157Or + 184.366Pa + 298.343Pl - 1.92W + 5130.38)	Wet (Wt %)	MJ/Kg	Uson, et al (2012)
Pl = plastics, Pa = paper, Fo = Food, Or = organic matters				

Since no calorific value analyses were performed on the inorganic fraction, to express calorific value per total commingled household solid waste the values reported here was multiplied by [1- inorganic fraction of the commingled MSW]. The inorganic fraction of the commingled household solid waste used in this research work ranged from 0.16 to 0.23.

4.6.4. Elemental/Nutrient Determination

Two to five kilogram household solid waste samples were collected for analysis of organic carbon, total nitrogen, total potassium, total phosphorus, and total sulfur as nutritional variables were measured following standard procedure and method. Samples were collected with plastic container from five sub-samples: food waste, yard waste, papers waste, plastics waste and textile waste components; samples were oven dried and stored in a refrigerator at 4 ^{0}C. Then all samples were transported to JIJE analytical testing service laboratory in an insulated box containing ice packs. Total nitrogen were determined AOAC official method (Kjeldahl method), organic carbon were analyzed by APHA 2540G. (loss on ignition at 550^{o}c), total phosphorus and potassium were determined using spectrophotometer and flame photometer, respectively following the procedures set for the parameter. Summary of parameters and their corresponding test methods are presented below.

Table 3: Summary of parameters and their corresponding test methods

S/N	Parameter	Test Method
1	Total Nitrogen (TN)	AOAC Official Method 978.04 – Kjeldahl Method
2	Organic Carbon (OC)	APHA 2540 G.-Loss on Ignition at 550 ^{o}C
3	Total Potassium (TK)	AOAC Official Method 923.03-Flame-photometer
4	Total Phosphorus (TP)	AOAC Official Method 985.35
5	Total Sulfur (TS)	FAO-Ash and Turbidimetric (Spectrophotometer) at 420 nm

The elemental analysis used to achieve/define the Carbon to Nitrogen Ratio (C: N) for biological conversion process Tchnobanoglous et al. 1993) calculated as Eq.(6)

$$C:N = \frac{\%\ \text{Carbon}}{\%\ \text{Nitrogen}} \qquad (6)$$

4.7. Solid Waste Bio-Char Production and Characterization

The samples used in this study were obtained from Jimma town households, these samples were mixed (mix of food, yard, paper, plastic and textile wastes) based on weight composition of solid waste components. The samples were initially dried in an oven (105^{o}c).

Bio-chars were produced over three hour and 20 minute periods using a slow pyrolysis process. Solid waste bio-char was produced in a batch pyrolysis unit at 400^{o}c. In these processes, the bio-char mass recovery was calculated as a percentage of the mass of feedstock input (dry wt. DW) and bio-char mass output (Bio-char mass DW/Feedstock mass DW). Similarly, to assess the suitability of using the solid waste bio-char for biological conversion, three samples (1 kg each) of household solid waste bio-char were taken. These samples were analyzed for pH, organic carbon, total sulfur and main nutrient contents (TN, TP, and TK). Total carbon and nutrient levels in addition to pH are considered as principal factors regulating the speed and degree of biological conversion of the waste (Zuccconi and Bertoldi, 1987).

The pH was measured by preparing a mixture of bio-char sample and deionized water (1:5). After approximately 5 hours, the measurements were taken with pH meter. For nutrient contents, the samples were first dried and then grinded into powder form. Kjeldahl method was used for determination of total nitrogen and loss on ignition at 550°C for organic carbon. Total potassium and phosphorous were determined by flame photometry and spectrophotometry methods, respectively.

4.8. Instrument

To carry out the analysis a number of items of equipment like hand protective plastic gloves for handling, hand push and horse drown carts and Bajaj car for transport of waste, scales of different ranges, plastic bag for collection and sorting of solid wastes, trash bag for collection of already processed wastes and photo cameras to record the research process. Different laboratory materials like dish, oven, and crucible were used to carry out the research process.

4.9. Operational Definition

- **Bio-Char:** also called solid product of biomass carbonization, a stable form of carbon, is produced from pyrolysis of biological materials.
- **Calorific Value/ Heating Value:):** is measured using a bomb calorimeter; and defined as the amount of heat released when dry solid waste is combusted and the products have returned to a temperature of 25°C. The heat of condensation of the water is included in the total measured heat. It is measured as a unit of energy per unit mass of substance (kcal/kg, kJ/kg).
- **Compost:** The controlled aerobic biological decomposition of organic matter, such as food, yard, paper waste and textile into humus, a soil-like material.

- **Density:** is the weight per unit volume of material (household solid waste). It is expressed in kilograms per cubic meter (kg/m^3).
- **Elemental Analysis:** It includes the quantitative determination of carbon, nitrogen, sulfur and potassium, Phosphorous within a solid waste material.
- **Higher Heating Value (HHV):** is the higher calorific value measured using a bomb calorimeter; the heat of condensation of the water is included in the total measured heat. It is measured as a unit of energy per unit mass of substance (kcal/kg, kJ/kg).
- **Lower Heating Value (LHV):** is defined as the net calorific value and is determined by subtracting the heat of vaporization of water vapor (generated during combustion of dry waste) from the higher heating value (kcal/kg, kJ/kg).
- **Pyrolysis:** are the thermo-chemical processes that convert solid waste into bio-char by heating the solid waste in the absence of air.
- **Recovery of Energy:** recoverable energy is stored in chemical form in all solid waste materials that contain hydrocarbons; this includes everything except metals, glasses, and other inorganic materials (sands, rags, plaster, etc).
- **Recovery of Materials:** recovered paper, plastic, rubber, fiber, metal, and glass can be re-used to produce similar materials.
- **Valorization of Waste:** refers to any activities aimed at reusing, recycling or composting of waste, useful products or source of energy.
- **Waste Composition:** is the term used to describe the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight.

4.10. Data Analysis

After checking the completeness, missing value, data were entered to computer, processed and analyzed using Microsoft Excel 2009 and then finally data were presented in tables, graphs. Generation rate of household solid waste was calculated from the studied household, average family size of the town (5.6) and total number of housing units (27,575). Data were presented as mean ± standard deviation.

4.11. Limitations of the study

Considering variations between days in waste composition and generation rate, a week round (seven days) sampling was conducted. However, due to lack of financial resource and time, seasonal variation was not considered. So the result may vary if repeated in different climate season.

The proximate analysis, calorific value and nutrient determination were intended to do in all solid wastes categories or components. However, due to budget constraint it was done only in five fractions like food, yard, paper, plastic and textiles wastes.

4.12. Quality Assurance

For the sake of data quality assurance sample collection and analysis was conducted carefully using standard operating procedures (Gidarakos et al., 2005) and double entry of data were performed to assure quality of data.

4.13. Ethical Consideration

The study was conducted after getting permission from ethical committee of Jimma University, college of public health and medical sciences. Waste segregation was performed in healthy condition with protective devices.

4.14. Dissemination Plan

The final result of this study was presented to Jimma University Public Health and Medical Science, Department of Environmental Health Science and Technology and was disseminated to concerning ministers, Oromia Regional State, Jimma Zone and other governmental and non-governmental organizations which are concerned with the study findings. Publication in national or international journal will also be considered.

CHAPTER FIVE: RESULT

5.1. Generation Rate and Waste Composition

The generation rate and composition of household solid wastes vary considerably according to changes in life style, commercial activities, population behavior, consumption patterns and economic growth rates that depend upon the season of the year, days of the week.

5.1.1. Waste Composition

Results of physical composition and typical percentage distribution of household solid waste are shown in Table 4.

Table 4: Average household solid waste composition percentage by weight in Jimma town.

Components	Average % by Wt. + SD
Food waste	31.58 ± 4.22
Yard waste	25.11 ± 2.28
Paper	6.06 ± 0.60
Plastics	10.09 ± 2.06
Textile	3.48 ± 0.41
Rubber and leather	0.76 ± 0.50
Glass and ceramic	1.67 ± 0.83
Wood	1.57 ± 1.10
Metals	0.27 ± 0.25
Miscellaneous	19.41 ± 2.18

NB: Miscellaneous component - including rock, sand, plaster, bones, ashes, paint strippers, batteries and paint residues, other organic & inorganic materials.

Food waste that include food left over, egg shells, fruit or vegetable peels, and cooked food left over comprise the largest component of Jimma town household solid waste stream account 31.58%. Yard waste comprises the second largest components, 25.11%, of Jimma town household solid waste stream. It includes grass clippings, leaves, and tree trimmings. Paper and paper products comprise 6.06% of household solid waste stream. The products that consists paper and paperboard wastes are newspapers, magazines, exercise books, tissue paper, cigarette packages, towels, paper plates, cups, corrugated boxes, milk cartons etc. Plastic products comprise 10.09% of the total household solid waste of the study area. The plastic product consisting mainly of plastic food items, trash bags, milk and water bottles, and soft drink bottles. Textile (occurred in discarded clothing, footwear) and rubber and leather products (occurred in bicycle tires, leather clothing and shoes) were found in Jimma town household solid waste stream in small amount (3.48 and 0.76% respectively). Glass products comprise 1.67% of the total household solid waste and occurred primarily in the form of containers as soft drink bottles, beer bottles, bottles and jars of food, and other consumer products. Metals comprising 0.27% of the total household solid waste consists mainly of aluminum foil, ferrous metals (iron and steel found in appliances, furniture, and corroded metal scrap, containers and packaging materials). Some hazardous materials were also recognized in household solid waste stream of study area such as paint strippers, batteries and paint residues.

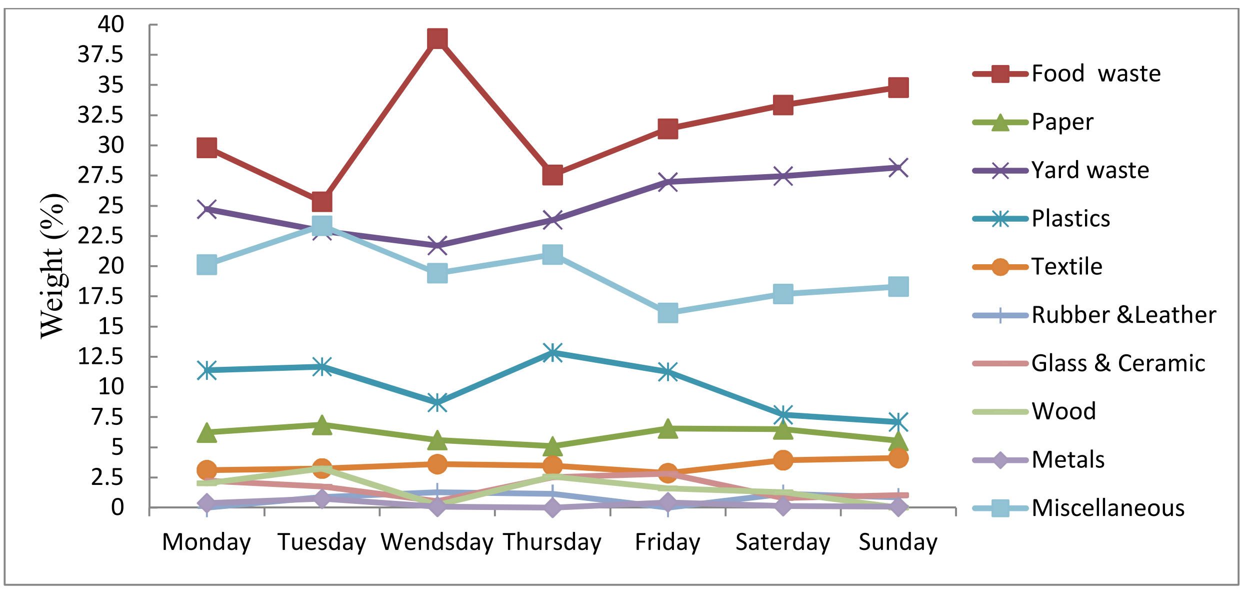


Figure 2: Variation of waste categories quantity during one week

5.1.2. Generation of Household solid waste

Results of solid waste collected from households in this study over the survey period (seven days) are summarized in Table 3. And Table 4 shows that household solid waste generation rates of an individual of Jimma town in day, week, month, and year. The result indicated that the household solid waste generation rate of Jimma city resident was 0.5 kg/capita/day (Table 5).

Table 5: Estimated household solid waste generation rates by weight and volume in a year in Jimma town

	Daily		Weekly		Monthly		Yearly	
	Wt. (Kg)	V (m^3)	Wt. (Kg)	V (m^3)	Wt. (Kg)	V (m^3)	Wt. (Kg)	V (m^3)
Per capita	0.50	0.002	3.48	0.014	14.93	0.061	181.67	0.744

5.1.3. Waste Density

Table 6 shows that the density of household solid waste components of Jimma town. The density of solid waste generated is ranging from 110.35 to 662.59 kg/m^3.

Table 6: Density of household solid waste by components

Components	Density (Kg/m^3)
Food waste	325.9
Paper	118.37
Yard waste	277.43
Plastics	110.35
Textile	186.18
Rubber and leather	152.17
Glass and ceramic	285.69
Wood	202.8
Metals	662.59
Miscellaneous	445.99

5.2. Analysis of Chemical Composition of the Waste

5.2.1. Proximate Analysis

Proximate analysis involves determination of moisture content, volatile matter, ash content and fixed carbon of sample. The analysis was performed according to ASTM method (Amin, 2011). The overall proximate analysis of wet waste samples is presented in Fig. 3 which shows that the average moisture content of household wet solid waste sample was 49.38 %, the volatile content was 41.01% and fixed carbon was 6.09%.

The result also indicated that paper waste has higher volatile matter (87.09%) next to plastic waste which had 93.93% volatile matter. And food waste had highest moisture content (69.96%) compared to other components

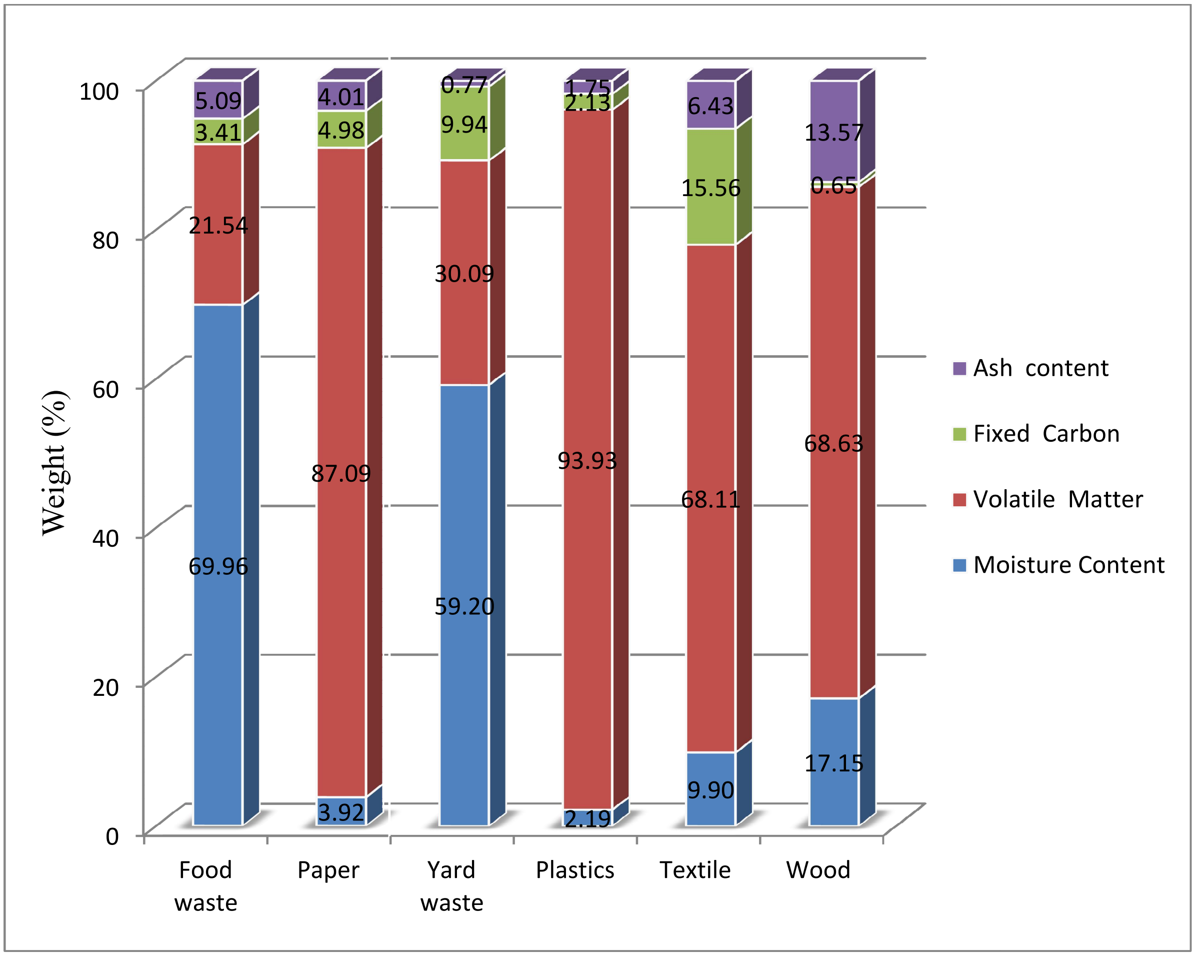


Figure 3: Obtained results from proximate analysis (wet basis) of collected sample at Jimma town residents

Proximate composition of solid waste shown in Table 7. The values in the table are percentages based on dry (moisture-free) content. Organic and combustible materials, such as paper and plastic are the components with high percentage of volatile matter usually between 85 to 97%.

Table 7: Representative proximate composition of household solid waste (dry basis) of Jimma town

Percent (%)	Tuesday	Thursday	Sunday	Average
Volatile Matter	76.53	79.14	75.9	77.19
Fixed Carbon	17.69	13.17	18.41	16.42
Ash Contents	5.78	7.69	5.69	6.39

5.2.2. Elemental Analysis

Table 8 shows that a comparative nutrient contents of household solid waste. Yard wastes had carbon contents of 46.73%. Plastics had the highest carbon contents among all components (52.4%). Textile had the lowest carbon content (37.96%) among household solid waste components. Food and paper waste had the carbon content of 45.77 and 45.69% respectively. Nitrogen was found in high contents in yard waste and textile waste 1.97 and 1.94% respectively. Paper products had nitrogen contents less than 0.34%. In general, a large variability in the nitrogen contents among all components was observed.

Table 8: Comparative Nutritional values and C/N ratio of Solid Waste and Chemical fertilizer

Components	MC Fraction	%OC	%TN	C/N	%TS	%TK	%TP
Yard waste	0.592	46.73	1.97	23.72	0.0045	2.73	0.15
Food waste	0.699	45.77	1.49	30.72	0.0061	2.30	0.14
Textile	0.099	37.96	1.94	19.57	0.0018	0.42	0.07
Plastics	0.0219	52.4	0.08	655.00	0.0021	0.45	0.003
Paper	0.0392	45.69	0.34	134.38	0.0019	0.21	0.03
Composite	0.493	47.02	1.41	33.35	0.004	1.48	0.08
Chemical Fertilizer (Gautam et al., 2010)		22	0.86	25.58	No Specs	0.75	0.18
MSW Compost Standard	< 50	> 25	> 1	< 25	No Specs	No Specs	No Specs
OC = Organic Carbon, TN = Total Nitrogen, TS = Total Sulfur, TK = Total Potassium, TP = Total Phosphorus, MC= Moisture Content, Specs = Specification							

5.3. Heating value (Calorific value)

5.3.1. Experimental Result Using Bomb Calorimeter

Calorific values for the components of household municipal solid waste are shown in Table 9. Plastic waste had highest calorific value of 40.81 MJ/kg. And Food waste had lower value of 11.10 MJ/kg.

Table 9: Energy contents (HHV) of household solid waste

Components	HHV (MJ/kg)	LHV (MJ/kg)
Yard waste	16.40	5.24
Food waste	11.10	1.63
Textile	16.03	14.20
Plastics	40.81	39.86
Paper	16.19	15.46
Composite waste	17.50	9.54
Net calorific Value (Composite SW)	9.54	
Moisture Content (%) (Composite SW)	49.38	

5.3.2. Mathematical Models Predicted Result

The graphical representation of the obtained HHV data base on compositional and proximate analysis is presented in Figures 4 and 5. This figure indicates the trend of the predicted HHV values as compare to selected different days of sampling period. The result of mathematical model prediction of the HHV of composite household waste shows that Eq. (7) has been 20.50 MJ/kg, Eq. (8) 20.20 MJ/kg and Eq. (9) 13.36MJ/kg (Fig.4).

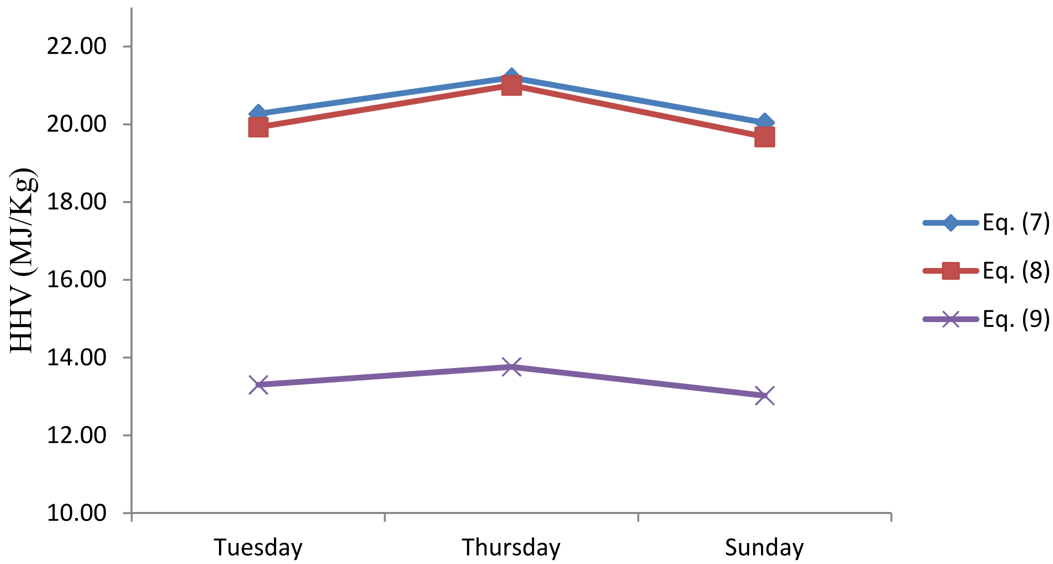


Figure 4: HHV values (MJ/kg) from model based on proximate analysis

Food waste, plastic and paper waste are the examples of components which contribute positively towards the calorific value (HHV). Eq.12 gave higher average HHV of 30.66 MJ/kg and Eq. 10 and Eq. 11 predicted the HHV of Jimma city household solid waste 21.61 and 20.52 MJ/kg respectively (Figure 5).

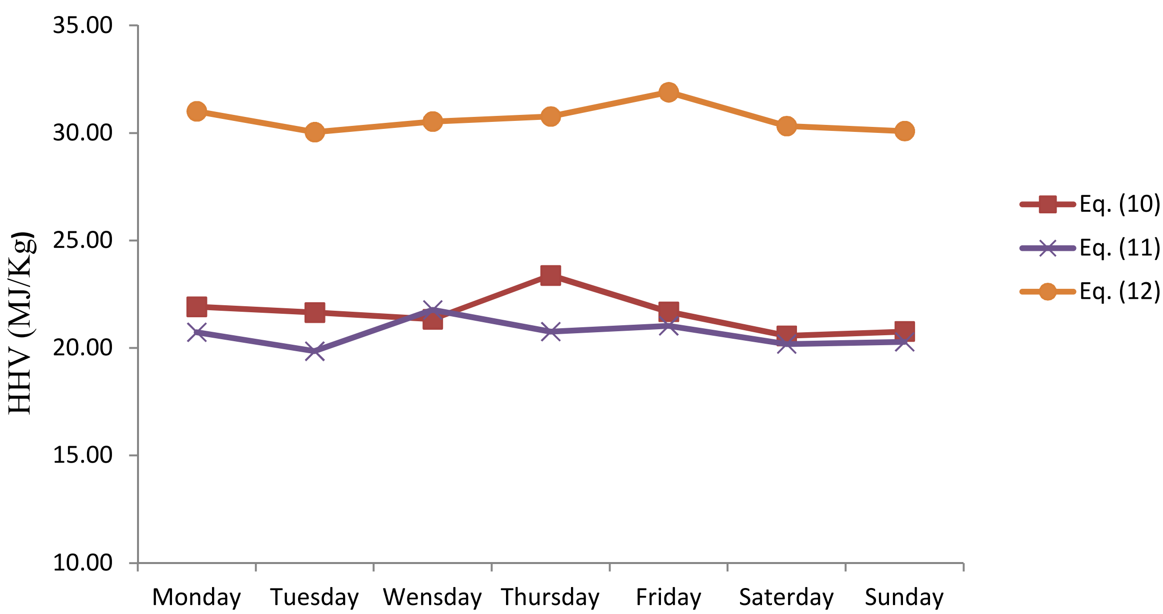


Figure 5: HHV values (MJ/kg) from model based on Compositional analysis**.**

5.4. Solid Waste Bio-char

5.4.1. Solid Waste Bio-Char Heating Value and Nutrient Determination

Bio-char is prepared from a variety of biomass. The Bio-char from household solid waste had higher Potassium (2550 mg/kg) than phosphorous (2121.50 mg/kg) and Sulfur (36.34 mg/kg). The Bio-char had a density of 0.45 kg/m^3. The results showed that the pH of Bio-char was near neutral (7.5) with the carbon and nitrogen content of 41.59 and 1.61% respectively (Table 10).

Table 100: Average Chemical Composition of Household Solid Waste Bio-Char.

Parameters	Average values	Standard Values Suitable for Composting
HHV (MJ/kg)	21.83	
LHV (MJ/kg)	9.84	
Density (kg/m^3)	0.45	
pH	7.5	5.5-8.0
Carbon (%dry basis)	41.59	30-40
Nitrogen (%dry basis)	1.61	> 0.6
C/N ratio (total dry basis)	25.83	25 - 50:1
Phosphorus (mg/kg)	2121.5	No specs
Potassium (mg/kg)	2550.37	No specs
Sulfur (mg/kg)	36.34	No specs

CHAPTER SIX: DISCUSSION

Composition describes the individual components that make up a solid waste stream and their relative distribution, usually based on percent by weight. A waste composition study, commonly known as waste sort, is needed to estimate the fraction of various waste material or items present in a waste stream. It is done for various projects, such as designing of recycling programs or finding out whether a waste is suitable for incineration. For this study it was done for finding out where a waste is suitable for energy recovery and nutrient.

Values based on percentage of collected household solid waste in Jimma town, it was evident that food waste (~ 31.58%) is the main constituent of waste stream. This result was in agreement with those results obtained for Ethiopian towns such as Hawassa town (Diriba, 2009), Dessie town (Cheru, 2011) where the food waste was found to be the major component of the solid waste stream generated. The study also shown that there were high variability in quantity of food and yard waste during the sampling period and yard waste fluctuated from 21.71 to 28.17% (Figure 2). Plastic waste was another important ingredient of household solid waste found to be of large amount, on average 10.09%. Another main component was the paper and textile waste which made about 6.06 and 3.48% of the total weight respectively. According to the result from sorting process, the amount of mixed paper, wood, glass and ceramics and metals that come from residential were not much different during the sampling period. The result also indicated that food waste, yard waste followed by plastic film make up the largest fraction of household solid waste of Jimma town residents.

In general, household solid waste in Jimma town was characterized by a high organic content with combustible matter consisting of food, yard, textile, paper, and plastic comprising 76.32% of the total waste suggesting that both decomposable and combustible matter were high. The estimate of the quantity of waste generation to be handled is crucially important to design collection services and disposal facilities. Because inappropriate recording of the amount of waste could lead to over or under provision of collection services or disposal facilities (Diriba, 2009).

The daily generation rate of household's solid waste in Jimma town varies from 0.42 to 0.61 kg/cap/day with average value of 0.50 ± 0.08 kg/cap/day. A similar survey conducted in Adama town indicates that it varies from 0.11 to 0.57 kg/cap/day (Lema, 2007). And in Makurdi, Nigeria it was about 0.54 kg/cap/day (Sha' Ato, et al., 2007). According to Tegegn (2008) the value of waste generation per capita of Jimma town household was 0.157 Kg/capita/day. Therefore, this indicates that the solid waste generation rates vary according to time, lifestyle of the people, urbanization and population growth.

The density of the sampled waste ranged from 116 to 260 kg/m^3 within a week study period. This is in agreement with values documented by (Peavy et al., 1985), which shows that none compact MSW densities range from 100 to 280 kg/m^3. The significance of density in MSW is that it enables to decide for storage, collection, transportation of waste, and in designing of sanitary and bioreactor landfills and the managers to plan and identify the capacity of waste haulage vehicles to be used (Gidarakos et al., 2005).

Selected individual waste component of the household solid waste was later subjected to proximate analysis for the determination of physicochemical properties. Proximate analysis (wet basis) in the study area showed household solid waste characteristics as: moisture 49.38%, volatile matter 41.21%, fixed carbon 6.10%, and ash content 3.31%. Moisture and ash content represent the noncombustible component of the solid waste. Both are undesirable in the waste as they add weight to the fuel without adding to the heating value. The volatile matter and the fixed carbon content are the preferred indicators of the combustion capability of solid waste (Amin, 2011). The awareness of physicochemical characteristics of waste helps in deciding and setting up a good waste processing and disposal facility in the city and in determination of efficiency of a waste treatment process (Sapna et al., 2013). The high percentage of the fixed carbon in waste materials such as textile (15.56%) and yard waste (9.94%) shows that this element requires a longer detention time on the surface of the furnace to achieve complete combustion compared to plastics waste, food waste and wood. The result also shows that the high percentage of ash content in textile, wood, food waste with 6.43, 13.57 and 5.09% respectively, dominating in the ash content percentage. The composite household solid waste has 41.21% volatile matter, which was portion of the wastes that is converted into the gas phases during the heating process (950°C).

The average value of moisture content was found to be 49.38 %. High moisture content of solid waste has negative and undesirable effect on applicability of the waste for energy recovery as it adds weight to the fuel without adding to the heating value (Das & Hoque, 2014). Result from moisture content analysis directly affected by the quantity of wet basis materials, such as yard waste and food waste in waste stream. Higher percentage of yard waste (28.17%) and food waste (34.79%) on Sunday compared with result on Tuesday (yard waste 22.92 % and food waste 25.33%) is the reason of increasing the percentage of moisture content.

Proximate composition of solid waste shows in Table 7 the values are percentages based on dry (moisture-free) content. Organic and combustible materials such as paper and plastic are the components with high percentage of volatile matter usually between 85 to 97%. Collected samples from households shows the higher volume of these materials on Thursday compare to other sampling days, is the reason on increasing the volatile matter up to 79.14%.

The estimation of the energy content of household solid waste can be of practical interest in the design and operation of the related energy conversion systems. Energy content of solid waste usually described in terms of HHV, LHV, Net Heating Value or Gross Heating Value. In this paper, the amount of heating value was determined by using experimental analysis and mathematical models based on compositional and proximate analysis. The experimental result indicated that the energy content of Jimma town households' solid waste was 17.50 MJ/kg as dry basis. The net calorific value (LHV) of the waste was 9.54 MJ/kg and a moisture content of 49.38% (Table 9). However, the moisture content was found to be higher than the desirable range (< 45), which is important waste parameters stated in Amanuel (2011) for technical viability of energy recovery through different treatment routes listed by (Amanuel, 2011). The calorific value of collected solid waste (17.50 MJ/kg) indicates that it can be incinerated without providing additional fuel and reveals the suitability of Jimma town household solid waste as energy recovery option. The acceptable recommended range of energy recovery from solid waste suggested by Whiting (2002) is 7.50 to 12.00 MJ/kg. Jimma town household solid waste has a comparative result of HHV with poultry pure waste (11.71MJ/kg), wheat straw (17.36 MJ/kg), sugar cane leaves (17.41MJ/kg), and cotton gin waste (17.48MJ/kg). The results indicated that such refuse is amenable to several disposal options with less adverse impact on the environment (Ojolo et al., 2008).

The calorific value of composite (mixed) households solid waste (9.54 - 17.5 MJ/kg) was approximately about one-half of the calorific value of coal (25-30 MJ/kg) and one-third of fuel oil (45 MJ/kg) and Natural gas (54.75MJ/kg) (Table 11). These might be depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (Peavy et al., 1985).

Table 111: Typical Calorific Values for Alternative Fuels/Raw Materials.

Fuel/Raw Materials	HHV (MJ/Kg)	Reference
Wood (soft wood)	20.00	(Demirbas, 1997)
Wood (red wood)	20.72	(Jenkins and Ebeling, 1985)
Peat	7.39	(Clemens et al., 1981)
Coal, Lignite	19.20	(Jigisha et al., 2005)
Coal, Bituminous	26.20	(Jigisha et al., 2005)
Coal, Anthracite	29.50	(Jigisha et al., 2005)
Fuel Oil	45.00	(Ityona et al., 2012)
Natural Gas	54.75	(Ityona et al., 2012)
Eucalyptus	18.64	(Jigisha et al., 2005)
Eucalyptus-Grandis	19.35	(Grover et al., 2002)
Wheat straw	17.36	(Grover et al., 2002)
Moringa-oleifera (leaves)	14.23	(Grover et al., 2002)
Sugar cane leaves	17.41	(Grover et al., 2002)
Tannery waste	7.87	(Grover et al., 2002)
Cotton gin waste	17.48	(Jigisha et al., 2005)
Poultry pure waste	11.71	(Grover et al., 2002)
HHs MSW (Jimma City)	17.50	**Present Study**
Red wood char (400 -550^{o}c)	28.84	(Jigisha et al., 2005)
Oak char (450 -650 ^{o}c)	24.80	(Jigisha et al., 2005)
Coconut shell char (750^{o}C)	31.12	(Jigisha et al., 2005)
Rice husk char	14.94	(Grover et al., 2002)
HHs MSW Char (400 ^{o}C)	21.83	**Present Study**

The elemental composition of MSW can significantly vary among countries, regions and cities, as a result of differences in the physical composition of MSW. The physical composition of MSW is usually dependent on the socio-economic conditions of a country, its population size, the climatic conditions and the national environmental legislation (Abu-Qudais and Abu-Qdais, 2000).

The knowledge of the calorific value of solid waste is necessary when it is to design waste to energy technology for energy recovery purposes. When direct calorific value measurements are not feasible, empirical models can be useful to predict the calorific value of solid waste (Liu et al., 1996). Several models (Table 2) have been developed to describe and predict the energy content of mixed solid waste. The common independent variables in such empirical models are either the elemental composition (Liu et al., 1996), the physical composition (Abu-Qudais and Abu-Qdais, 2000) and the proximate composition (i.e., the content in volatile matter, moisture, fixed carbon) of MSW (Kathiravale et al., 2003).

Proximate analysis models were created based on the weight of percentage of the volatile matter, fixed carbon and moisture contents in solid waste (Kathiravale et al., 2003). The advantage of using proximate analysis data was that it gave result based on sample sizes where about Eq. (7 – 9) (Liu et al., 1996). Figure 4 shows some of the common models that have been used to estimate the HHV according to proximate analysis result. The positive point is that, these models do give an accurate estimation of the calorific values of the samples (Abu-Qudais and Abu-Qdais, 2000; Amin, 2011; Liu et al., 1996). As figure 4 shows there is small difference between the results from Eq.7 (20.50 MJ/kg), Eq.8 (20.20 MJ/kg) and they gave almost good prediction of HHV values as compare to Eq. 9 (13.36 MJ/kg).

Based on compositional analysis the predicted HHV values as compared to selected different days of sampling period food waste, plastic and paper waste are the examples of components which contribute positively towards the calorific value. Plastic as an individual component accounted about 10.09% of the total daily disposal household solid waste of the study area and contribute greater value the heating value followed by paper and yard waste. Increasing the amount of plastic in waste stream on Thursday compared to Wednesday was a reason for obtaining higher volatile matter and higher value of HHV in that day. As Figure 5 showed, Eq.10 and Eq.11 gave also good prediction of HHV values.

Thus, Eq.7 (20.50 MJ/kg), Eq.8 (20.20 MJ/kg), and Eq.11 (20.52 MJ/kg) are the best model in this category compared to the laboratory result (17.50 MJ/kg). The finding of proximate and compositional analysis results strengthen the argument that models are best suited in their own area and this finding is precise and accurate in predicting the HHV of household solid waste in Jimma town.

The ratio of carbon to nitrogen (C/N ratio) is an indicator of the compostability of materials. Table 7 shows representative C/N ratios of compostable components of Jimma town household solid waste, which vary from 19.57 to 655, due to their high carbon contents and the low nitrogen contents of paper and plastics wastes have high C/N ratio. The chemical composition shown above indicates that the waste, except plastic and paper waste, can be composted and used as a fertilizer due to the fact that the carbon to nitrogen mass ratio occurs within the optimum range for waste to undergo biodegradation. To maximize the composting rate while minimizing odor generation, a C/N ratio of 20/1 to 30/1 is considered optimum. Higher ratios reduce the composting rate, while lower ratios invite odor problems (Zuccconi & Bertoldi, 1987). Composting of paper and plastic waste, with a C/N ratio of 134.38 and 655 respectively, is difficult unless large quantities of another material, such as yard waste, food waste are mixed in to reduce the ratio. The organic fraction of composite household solid waste that includes plastics has a C/N ratio of around 33.35. The C/N ratio moves above the optimum level as quantities of plastic waste are added to the mixture, however yard and food waste serve as effective bulking agents in composting or removing plastic waste from the quantity gave the C/N of 28.48, which is also ideal for composting. This study also revealed that the C/N mass ratio ranged from 23.24 to 35.29 for different combination of the waste components generated from Jimma city households (Annex 2). Previous work by Peavy et al. (1985) shows that at the optimum C/N ratio of 30, there is adequate nitrogen for cell synthesis and carbon for energy source.

Bio-chars were produced by pyrolysis of household solid waste. Pyrolysis is the chemical decomposition of an organic substance by burning in the absence of oxygen. The high temperatures used in pyrolysis can induce polymerization of the molecules within the feedstock, whereby larger molecules are also produced (including both aromatic and aliphatic compounds), as well as the thermal decomposition of some components of the feedstock into smaller molecules (Jeffrey, et al., 2009). During the pyrolysis or oxidation process that generates bio-char; heating causes some nutrients to volatilize, especially at the surface of the material, while other nutrients become concentrated in the remaining bio-char (Jeffrey, et al., 2009). Nitrogen is the most sensitive of all macronutrients to heating; thus the N content was higher (1.61%). The pH measured in 1:5 solid water suspension, was neutral (7.5). The study also revealed that the C/N mass ratio of the bio-char waste components was 25.83. Therefore, Bio-char is likely more important as a soil conditioner and a driver of nutrient transformations and so as a primary source of nutrients.

With regard to agronomic parameters, the quantities of essential plant nutrients, especially nitrogen (1.41%), phosphorous (0.08%) and potassium (1.48%) of household solid waste and nitrogen (1.61%), phosphorous 2,121.5mg/kg (0.21%) and potassium 2,550.37 mg/kg (0.26%) of solid waste bio-char were found to be in acceptable concentration for soil conditioning and eco-friendly cheap and best as compare to chemical fertilizer. However, according Zuccconi and Bertoldi, 1987 and Jilani, 2000 the excellent quality of compost contains high percentage of nitrogen content (>1%), whereas no specific international standard has yet been set for phosphorous and potassium concentration content. Therefore, its use in soil may add compost and improve the aeration, aggregation and water holding capacity (Jilani, 2000).

High biodegradable organic fraction (~62.75%) and good nutrient contents suggest the applicability of Jimma town household solid waste stream for implementing composting operations. Even though Jimma town is located within the best of Ethiopian areas, conducive for agricultural production with abundant annual rainfall, applying compost as soil amendment will be valuable as it will improve the soil fertility by supplying main nutrients such as TN, TP, TK, as well as increase water holding capacity due to its high organic matter content.

The heating values for various bio-char samples in the literature were presented in Table 8 to make a comparison between different biomass feedstock. As can be seen from Table 11, the heating values of biomass derived bio-chars in the literature vary between 11.83 and 44.2 MJ/kg, whereas the values for Jimma town household solid waste bio-char was 21.83 MJ/kg. Generally, the high heating values of bio-chars make them attractive feeds for energy production instead of fossil-based solid fuels. And bio-chars can be alternative to the conventional fuels partially due to their high calorific value.

Hence, for the Jimma city, composting, thermo-chemical conversion (pyrolysis) can be considered as the best options for the biodegradable fraction after segregating recyclables components.

CHAPTER SEVEN: CONCLUSION AND RECCOMENDATION

7.1. Conclusion

Solid waste is a domestic energy resource with the potential to provide a significant amount of energy. The amount of this energy identified as an important issues affecting the suitability of design the waste to energy plan. The good average amount of heating value (about 17.50 MJ/kg) of collected household solid waste from Jimma town shows the feasibility of design the waste to energy plan such as pyrolsis in the study area.

The HHV estimated from some models were found to be closely match with the value determined from laboratory experiment. Thus, models are reliable in predicting the energy recovery potentials from different solid waste components and the quantity of energy obtainable from a known amount and composition of mixed solid waste can be estimated without conducting calorimetric experiments.

The biodegradable fraction and the nutrient composition of solid waste bio-char are within the acceptable range. Thus, the waste can be considered as suitable for soil conditioning. As such, an economic benefits can be obtained from the waste while avoiding the cost of waste management.

Further separation of recyclable fraction of rubber, leather, glass, ceramic, wood, and metals from the waste would be helpful and can reduce the total waste disposed. Thus if energy recovery, composting, and recycling were applied, more than 80% of the total waste stream can be used as a source materials leaving only 19.41% to be disposed at the landfill. This will decrease the cost and environmental footprints dramatically.

7.2. Recommendation

Since there are no waste treatments facilities present in the town and waste management simply is a linear system of collection and disposal without any source segregation, creating health and environmental hazards, responsible body should look after this problem otherwise the town solid waste management division should look other solid waste management options like composting, recycling and energy production because as observed from the study result the composition of solid waste in the study area is suitable for other disposal options other than landfilling.

The calorific value of Jimma town household solid waste make them attractive feeds for energy production instead of fossil-based solid fuels and can be alternative to the conventional fuels. Therefore, Jimma town administration should implement waste to energy technology for both waste management and energy recovery. But, the implementation of waste to energy schemes should not be done in haste, rather should first proceed cautiously in pilot schemes, which may then transform into large-scale schemes. Thus based on the those available data of solid wastes in Jimma town composting and waste to energy transformation are recommended.

A household solid waste quantity and composition study should be conducted during a rainy season in order to get more year round data on waste generation and composition. Since the study was conducted only for household solid waste similar studies should be conducted in other waste sources like commercials, institutions, and street to have full information of MSW of the town.

Additional analysis to measure more parameters such as fusion point of ash, halogens, hydrogen, oxygen, and heavy metals would be required to gain a more complete picture about the chemical composition of solid waste in Jimma town.

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ANNEXES

ANNEX 1. Data sheet for waste collected characterization from individual household.

1. Data sheet for waste collected from individual household.

House No. /Code	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Total	
	Wt	**V**	**Wt**	**V**	**Wt**	**V**	**Wt**	**V**	**Wt**	**V**	**Wt**	**V**	**Wt**	**V**	**Wt**	**V**
Total																

2. Data sheet for composition (weight kg and volume) for the waste collected from all income groups.

WASTE CHARACTERIZATION ANALYSIS DATA SHEET

NAME OF HOUSEHOLD ---
CONTACT ADDRESS ---
SAMPLE ADDRESS / IDENTIFICATION CODE: ------------------------------------
SAMPLING DATE: --
GROUP NUMBER: --
TOTAL WEIGHT OF SAMPLE COLLECTED: ---

Components	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Total	
	Wt	V	Wt	V	Wt	V	Wt	V	Wt	V	Wt	V	Wt	V	Wt	V
Food waste																
Paper																
Yard waste																
Plastics																
Textile																
Rubber & leather																
Glass & Ceramic																
Wood																
Metals																
Miscellaneous																
Total																

3. Description of components of Household Municipal Solid Waste

Category	Description
Food waste	All food waste type includes discarded meat scraps, dairy products, egg shells, fruit or vegetable peels, and other food items from homes excluding bones.
Yard waste	Branches, twigs, leaves, grass, & other plant materials
Paper	All types of paper including Mixed colored paper, magazines, newspaper, office & computer paper, Kraft, etc
Glass *	Clear & colored glass
Plastics	All types of plastics
Metals*	Iron, steel, tin can, & bi-metal cans
Wood	Lumber. wood products, pallets, & furniture
Textile	Clothing, footwear, covered furniture, mattresses, etc
Rubber and leather	Tires, wire cords, gaskets(rope), leather shoes, leather bags, or leather belts
Miscellaneous *	Other organic & inorganic materials, including rock, sand, , plaster, bones, ashes, battery etc

*** Indicates the non-combustible parts, not included in the proximate & Heat value analysis**

ANNEX 2.

Total quantities of solid waste collected from sampled households.

Components	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**	**Average**
Food waste	95.62	82.68	149.16	93.58	116	153.72	163.92	122.10
Paper	19.98	22.42	21.54	17.32	24.26	29.96	26.10	23.08
Yard waste	79.3	74.82	83.38	80.94	99.7	126.6	132.72	96.78
Plastics	36.5	38.12	33.44	43.62	41.6	35.48	33.44	37.46
Textile & Leather	9.98	10.6	13.86	11.82	10.6	18.14	19.36	13.48
Rubber	0	2.84	4.90	3.88	0	5.3	4.08	3.00
Glass & Ceramic	7.14	5.70	2.06	8.56	10.40	3.66	4.90	6.06
Wood	6.52	10.6	0.82	8.76	5.92	5.92	0	5.51
Metals	1.22	2.44	0.3	0	1.64	0.62	0.4	0.95
Miscellaneous	64.57	76.19	74.58	71.21	59.64	81.59	86.29	73.44
Total	320.83	326.41	384.04	339.69	369.76	460.99	471.21	381.85

Laboratory result, Energy content (Calorific value) of household solid waste

Field No.	Lab. No.	Calorific value (cal/gm)	Calorific value KJ/Kg
Yard waste	6247/14	3919.91	16411.87919
Food waste	6248/14	2649.76	11094.01517
Textile	6249/14	3829.83	16034.73224
Plastics	6250/14	9747.08	40809.07454
Paper	6251/14	3867.54	16192.61647
1cal = 4.1868J			

Laboratory result of Elemental/ Nutrient determination of household solid waste

Components	**%OC**	**%TN**	**TS** mg/Kg	**TK** mg/Kg	**TP** mg/Kg
Yard waste	46.73	1.97	44.78	27250	1473.75
Food waste	45.77	1.49	61.07	23000	1368.13
Textile	37.96	1.94	17.9	4230.96	670.25
Plastics	52.4	0.08	21.03	4450.87	28
Paper	45.69	0.34	19.27	2117.59	270.25

Comparative average nutritional values and C/N ratio of HHs SW

Mixed Components	C (%dry basis)	N (%dry basis)	C/N ratio
ya+Fo+Tex	45.72	1.73	26.41
Ya+Fo+Tex+Pa	45.71	1.6	28.48
Fo+Tex+Pa	45.09	1.35	33.29
Ya+Pa	46.53	1.67	27.82
Fo+Pa	45.76	1.3	35.29
Ya+Fo	45.66	1.97	23.22
Ya+Fo+Pa	46.15	1.72	26.86
ya = yard waste, Fo = Food waste, Pa = paper waste, Tex = Textile waste			

ANNEX 3.

Laboratory procedure for proximate analysis

Moisture Content Determination

- Heat the muffle furnace to 750^{o}c and place previously ignited porcelain crucibles
- Covers in the furnace for 10 minutes.
- Cool the crucibles in desiccators for 1 hour.
- Weigh the crucibles and add to each approximately 1 gram of sample

- Place the samples in the oven at 105^{o}c for 1 hour.
- Place the dried samples in desiccators for 1 hour and weigh.

- The samples shall be considered oven dry when the decrease in weight of consecutive weighting is 0.005g or less. Succeeding drying periods shall not less than 1 hour.

Volatile Matter Determination

- Heat the muffle furnace to 950°c
- Preheat the crucibles for the moisture content determination, with lids in place and containing the sample, as follows: with the furnace door open, for 2 minutes on the outer edge of furnace (300°c) and then for 3 minute on the edge of furnace (500°c)
- Then move the samples to the rear of the furnace for 6 minute with the muffle door closed.
- Cool the samples in a desiccators for 1 hour and weigh.

Ash Content Determination

- Place the samples in the furnace at 750°c for 1 hour.
- Cool the crucibles with lids in place in desiccators for 1 hour and weigh.
- Repeat burning of the samples until a succeeding 1 hour period of heating results in a loss of less than 0.0005g.