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ASSESSMENT OF LIGNOCELLULOSIC CROP WASTE BIOMASS POTENTIAL FOR BIOFUEL PRODUCTION IN LAWRA-NANDOM DISTRICT

By

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DECLARATION

I, Ayamga Ezekiel Anabire, the under signed, declare that this thesis is my original work and has not been presented for a degree in any other University. All sources of material used for this thesis have been duly cited and acknowledged.

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ABSTRACT

The aim of this study was to assess crop residue biomass potential for second generation biofuel production in the Lawra-Nandom district of Ghana. The specific objectives of the study were: (1) to estimate present and future crop residue biomass with corresponding second generation biofuel production potential and compare with present fuel demand; (2) to evaluate energy balance of ethanol production from crop residue biomass and; (3) assess the financial viability of possible projects. The methods used in this study for data collection included interviews, survey, field and laboratory experiment.

The residue to product ratio of four major crops–maize, sorghum, millet and groundnut stalks as determined in the field were 1.15, 4.75, 5.53 and 1.73 respectively. The findings show that the total annual crop residues production in the Lawra-Nandom district was about 272,000 tonnes. Among the major crops grown in the district, sorghum crop generates the largest quantity of residues, contributing 59% by weight of the total residues. Ethanol production potential was estimated to be 40 million litres if 40% of the average residue generated between 2003 and 2012 were used for energy purposes. The research also estimated that the crop residues produced in the Lawra district will be able to produce enough bioethanol to meet the current and future fuel demand of the district. The net energy balance of the biofuel production process was estimated to be 1,718.7 MJ with a ratio of energy output to input being 1.31– this means the production process is beneficial. From the financial analysis, the net present value was calculated to be GHC 2 million with an internal rate of return of 19.3% – this implies that it is financially viable to establish a bioethanol plant in the district.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Humans have three basic needs namely food, water and shelter. These needs cannot be met without energy. Energy is therefore being viewed as the lifeblood of our society and economy. It is needed for mobility, cooking, heating and cooling homes (Hamilton, 2002) as cited by Smith (2008). However, ensuring access to sustainable energy has recently become an issue of public concern. Energy crisis is one of the most difficult challenges faced by humankind in the 21st Century (Rajvanshi, 2010) as the world becomes increasingly dependent on fossil oil.

Global energy consumption is projected to increase by 36% by 2030 (British Petroleum, 2013). In Africa, oil consumption could double in that time (US Department of Energy, 2007) as cited in GTZ/MOFA-Kenya (2008). Since the transport sector relies almost entirely on oil supplies for fuel, countries will have to keenly compete for this limited supply of oil and this poses more challenging issues.

In fact, several factors such as energy price increases, increased market volatility (partly during 2008 and 2009), heavy dependence of many countries on imported oil, lingering debate about the ultimate size of remaining, recoverable fossil fuel reserves and the growing concern about the environmental impact of fossil fuel usage have provided impetus for the current strong interest in and support for alternative sources of energy in many parts of the world (Mandil and Shihab-Eldin, 2010).

Africa continues to face great challenges; it is still far from achieving the Millennium Development Goals (MDGs). To date, around half of Africa's population live in absolute poverty with about 70% depending on traditional biomass as their only source of fuel. The lack of access to reliable, clean and affordable energy services in Africa is seriously hampering all efforts for more economic growth and less poverty (Forum for Agricultural Research in Africa and International Institute for Water and Environmental Engineering, 2008).

Africa has vast land, varieties of biofuel feedstocks, favourable climate for growing energy crops and low labour cost ought to take advantage of emerging biofuel industry. Promotion of biofuels industry in developing countries has the capacity to propel such countries to achieve the MDGs through poverty reduction (especially job creation and economic enhancement), health impact (especially reduction in indoor pollution) and climate change mitigation (Adarkwah *et al.*, 2007).

Biomass is Ghana's dominant energy resource in terms of endowment and consumption (Ministry of Energy, 2010). The primary energy supply in the country is based on biomass mainly firewood and charcoal (42%), petroleum (47%), natural gas (3%) and electricity (8%) (Energy Commission of Ghana, 2014). Biomass resources cover about 20.8 million hectares of the 23.8 million hectare land mass of Ghana. The vast arable and degraded land mass of Ghana has the potential for the cultivation of crops and plants that can be converted into a wide range of solid and liquid biofuels (Ministry of Energy, 2010).

Zuzarte (2007) stated that cooking represents a major source of energy consumption in most developing countries particularly in rural areas. The author noted that inefficient use of traditional biomass presents a major environmental and health concern such as indoor air pollution caused by burning biomass and coal in residences. The author further claimed that the unsustainable use of firewood or preparation of charcoal contributes to the degradation of the local environment.

Batidzirai *et al.* (2006) as cited by Chagwiza (2008) viewed modern biofuels as promising long- term renewable energy sources, which have the potential to address environmental impacts, rising fossil fuel prices as well as security concerns posed by current dependence on fossil fuels. The author further commented that biofuels could provide new income and employment opportunities for rural farmers. On account of this, biomass-based energy is a promising alternative to fossil fuels because of the versatility of its use and reduced dependence on foreign fossil fuels which are expensive to import.

In a quest to promote biofuel production and usage in Ghana, the government produced the Strategic National Energy Plan (SNEP Report) in 2006 which mandates 10% blends of bioethanol (E10) and biodiesel (B10) with petrol and diesel by 2020 (Energy Commission, 2006).

The above challenges have led many developing and developed countries to consider biofuel as an alternative source of energy. The Ghanaian economy, for instance has experienced shocks due to the volatile and high petroleum prices (Bank of Ghana, 2012).

Therefore, this makes economic development unsustainable. In view of the above challenges, there is the need for alternative source of fuels and biofuels are seen as perfect substitutes in place of conventional fuels. Hence, there is the need to identify feedstocks that are economically, socially and environmentally sustainable for biofuels.

1.2 PROBLEM STATEMENT

According to Ghana's central bank monetary policy report (Bank of Ghana, 2014), the sharp rise in crude oil prices on the international market is increasing the depreciation of the local currency and may heighten inflation by causing manufacturing input prices to move upwards which could lead to slowdown in economic activities. There is therefore the need for the country to focus attention on domestically produced biofuels in order to reduce the challenges posed by oil importation.

Ghana's Energy Commission, the agency in charge of energy planning in Ghana, posited that the development of biofuel will enable Ghana achieve its strategic energy objectives which include energy security, reducing oil bill and saving foreign exchange, climate change mitigation, poverty alleviation and wealth creation through employment generation. The Commission has set a target for Ghana to substitute national petroleum fuels consumption with biofuel by 10% by 2020 and 20% by 2030 (Energy Commission, 2010). The biofuels needed to meet the 10% target in 2020 is estimated at about 336 million litres (Antwi *et al.*, 2010). To meet this demand requires abundant information on feedstock sources. Even though there is a general belief that biomass feedstocks abound in Ghana for biofuel production, it appears there is insufficient data and knowledge relating to the subject and this demands for research.

Research on feedstock for biofuel production in Ghana is limited and most researchers focus their attention on first generation feedstocks such as sugar cane, cassava, oil palm and cereal grains for biofuels (Kemausuor *et al.*, 2013; Osei, 2013; Afrane, 2012, Caminiti *et al.*, 2007). However, producing biofuels from these first generation feedstocks present social challenges with respect to land grabbing that could potentially cause food supply shortages (Boamah, 2014a; Boamah, 2014b; Schoneveld *et al.*, 2011). Also, first generation biofuels may not be the answer to climate change mitigation as previously envisaged.

Crop residues and biomass from other waste sources are more suited feedstocks for biofuels production with regards to social and environmental benefits and are envisioned as an attractive solution to the aforementioned problems associated with the production of first generation biofuels. According to Kumarappan (2011), biofuels produced from lignocellulosic biomass feedstocks offer a number of potential benefits and could serve the purpose of sustainability. The raw materials used are largely waste materials from agriculture, forestry or other non-food crops. The use of wastes overcomes the problems of using food and feed grains such as corn, for biofuel. Also, cellulosic biofuels help reduce greenhouse gas emissions relative to fossil fuels and other biofuels, such as corn ethanol. Research into second generation biofuels in Ghana has so far only considered feedstock availability and not much has been done in the analysis of other important factors such as energy balance and economic analysis (Kemausuor *et al.*, 2014; Mohammed *et al.*, 2013; Duku *et al.*, 2011).

From the literature, no research has been reported on second generation biofuel production potential from agricultural residues in the Lawra-Nandom district. It is against this background that this study is set out to assess lignocellulosic agricultural crop waste biomass potential for sustainable biofuel production in the Lawra-Nandom district.

1.3 RESEARCH QUESTIONS

a) What is the current traditional fuel demand in the studied district?

b) Does second generation biofuel production from agricultural crop waste biomass have the potential to meet the current and future fuel demand in the studied district?

c) Does second generation biofuel production from agricultural crop waste biomass offer environmental benefits in terms of energy balance?

d) Is it financially viable to produce second generation biofuel from agricultural crop waste biomass in the studied district?

1.4 AIM AND OBJECTIVES OF THE RESEARCH

The main aim of this research is to provide an objective and comprehensive assessment of agricultural crop waste potential for second generation biofuel production in the Lawra-Nandom district. The research seeks to answer the four critical questions stated above.

In order to address the above questions, specific objectives were developed which include:

I. To estimate present and future crop residue biomass with corresponding second generation biofuel production potential in the Lawra-Nandom district and compare with fuel demand

II. To evaluate energy balance of ethanol production from crop residue biomass

III. To assess the financial viability of possible projects.

1.5 JUSTIFICATION OF THE STUDY

Biofuels are new areas of the energy sector in Ghana; therefore, there is insufficient research in this field. The assessment of agricultural crop waste biomass potential for sustainable second generation biofuel production at the district level would provide vital information that could assist in the formulation of policies and institutional reforms to facilitate reduction in environmental degradation and engender socio-economic development in rural areas as a result of the additional income farmers would get from agricultural waste biomass feedstock. Agricultural waste biomass is a potential solution to the food versus fuel debate.

Furthermore, the study will provide information that could be used to facilitate the integration of biofuels from agricultural waste into development programmes in the country such as the Savannah Accelerated Development (SADA) project and others. Additionally, it is expected that the study will contribute significantly to enable Ghana achieve its strategic energy objectives which include energy security, reducing the oil bill and saving foreign exchange, climate change mitigation, poverty alleviation and wealth creation through employment generation by providing reliable information. The study would also provide residue- to- product ratio (RPR) data on major crops in the district which could be used by both researchers and policy makers.

1.6 SCOPE AND LIMITATION OF THE STUDY

The study was conducted in the Lawra-Nandom district of the Upper West Region of Ghana. Biofuels have various applications. This study is limited to bioethanol for transportation and cooking. Furthermore, lignocellulosic agricultural crop waste biomass feedstocks for bioethanol production are the main focus of this study. The study only assesses feedstock potential, energy balance and financial viability of bioethanol production from lignocellulosic agricultural crop waste biomass via biochemical route.

1.7 OUTLINE OF THE STUDY

The study is organised into five chapters. The first chapter is the introduction to the study. The second chapter presents a comprehensive literature review on the utilization of lignocellulosic biomass for biofuel production. Chapter three consists of the research methodology and describes the study area, the methods used in data collection and the analysis. Chapter four presents the results of the study whilst Chapter five presents the key findings and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter seeks to present a comprehensive literature review on the conceptual and theoretical foundation of biomass and biofuel production. The chapter begins with the general overview and fundamental concepts of biomass as well as biofuels. The study focuses much interest and attention on lignocellulosic biomass and biofuels. The main sources of information for the literature review include relevant text books, articles, journals, web sites/internet and other credible sources of information relevant to this study.

2.1 FUNDAMENTAL CONCEPTS OF BIOMASS

2.1.1 GENERAL OVERVIEW OF BIOMASS

Biomass, for most of history, has been the primary energy source powering human development. This energy supply has taken various forms, including wood and dung for cooking and heating and charcoal for metallurgy. Biomass can be utilized for the production of process heat, steam, motive power, and electricity, and can be converted by thermal or biological routes into a range of useful energy carriers such as liquid fuels and synthesis gas. Indeed, until the widespread utilization of crude oil as an energy source in the 19th Century, biomass supplied the majority of the world's energy needs. In recent days, concern over the environmental effects of fossil-fuel combustion, as well as disquiet about dwindling petroleum reserves–coupled with increasing global energy demand–have brought about a resurgence of interest in the utilization of biomass as an energy source (Crocker and Andrews, 2010).

Biomass is formed from living species like plants and animals—that is, anything that is now alive or was a short time ago. It is formed as soon as a seed sprouts or an organism is born. Unlike fossil fuel, biomass does not take millions of years to develop. Plants use sunlight through photosynthesis to metabolize atmospheric carbon dioxide and grow. Animals grow by taking in food from biomass. Fossil fuels do not reproduce whereas biomass does, and, for that reason, is considered renewable. This is one of its major attractions as a source of energy or chemicals (Basu, 2010).

Biomass-based energy is the oldest source of consumer energy known to mankind, and is still today the largest source of renewable energy, accounting for roughly 10% of world total primary energy supply (International Energy Agency (IEA), 2011) as cited in OECD/IEA (2012). Most of this traditional biomass plays an important role in providing energy for cooking and heating, in particular to poor households in developing countries.

Biomass is a unique source of renewable energy as it can be provided as solid, gaseous or liquid fuel and can be used for generating electricity, transport fuels, as well as heat – in particular, high temperature heat for industry purposes (IEA, 2012).

2.1.2 DEFINITION OF BIOMASS

United Nations Framework Convention on Climate Change (UNFCCC, 2011) defined biomass as a non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms. The definition also include products, by-products, residues and waste from agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes.

According to Oliveira and Franca (2009), biomass can be used as a liquid energy source by means of thermal/chemical/biological conversion.

According to the Biomass Research and Development Board of the US (2008), biomass can be biochemically processed to extract sugars, thermochemically processed to produce biofuels or biomaterials, or combusted to produce heat or electricity.

Macmillan (2001) asserted that biomass is the totality of the earth's living matter that is derived from the process of 'photosynthesis' either directly or indirectly. The author further explained that biomass exists on the planet in a thin surface layer called 'biosphere'. Furthermore, the author stated that, the biosphere accounts for a fraction of the mass of planet earth but holds an enormous storehouse of energy. This store of energy has at its heart, the sun and the source is being continually replenished.

2.1.3 CLASSIFICATION OF BIOMASS FEEDSTOCKS

According to Zhang (2010), biomass feedstocks used for producing biofuels can be grouped into two basic categories:

1. **First-generation** feedstocks, which are harvested for their sugar (e.g., Sugar crops such as sugar cane, sugar beets, molasses and sorghum), starch (e.g., starch crops such as corn, millet, grain sorghum and other cereals/grains) and oil content (e.g., oil crops such as soybean, palm oil, coconut oil, etc)

2. **Second-generation** (lignocellulosic) feedstocks, which are harvested for their total biomass (e.g., energy crops such as switchgrass, agricultural and forest residues).

Agricultural crop residues are classified into crop residues and agricultural industrial by-products (Schoneveld *et al.,* 2010) as cited by Duku *et al.* (2011). According to Duku *et al.* (2011), crop residues are the materials left or burnt on the farms after harvesting the target crops. The authors stated that crop residues in Ghana include straw, and stalk of cereals such as rice, maize (corn), sorghum, and millet, and cocoa pods. Agro-industrial by-products, on the other hand, are produced mainly after crop processing, and include cocoa husk, coconut shell and husk, rice husk, oilseed cakes, sugarcane bagasse, and oil palm empty fruit bunch.

Forest residues include logging residues produced from harvest operations, fuel wood extracted from forestlands, and primary and secondary wood processing mill residues (Perlack et al., 2005) as cited by Carriquiry *et al.* (2010).

According to Milbranbt (2009) as cited in Agbro and Ogie (2012), forest residues include wood residue or wastes from logging and wood-processing activities. The author stated that logging residues are the unused portions of trees cut during logging operations and leaf in the woods. These include stumps, branches, leaves, off-cuts, and sawdust. wood processing residues, or primary mill residues, are composed of wood materials (such as discarded logs, bark, sawdust and shavings) generated at manufacturing plants – sawmill, veneer mill, plywood mill, or pulp mill- when round-wood are processed into primary wood products.

Dedicated energy crops include fast-growing woody plant species like willow (*Salix spec.*), poplar (*Populus spec.*), eucalyptus (*Eucalyptus spec.*) and others, as well as herbaceous plant species like miscanthus (*Miscanthus spec*.), switchgrass (*Panicum virgatum*), Johnson grass (*Sorghum halepense*) and others. Both types of energy crops are cultivated in perennial plantations with typical rotation periods of three to seven years for woody plants and one year for herbaceous plant species (Rosillo-Calle *et al.*, 2006) as cited in IEA (2010).

2.1.4 COMPOSITION OF LIGNOCELLULOSIC BIOMASS

Plants capture solar energy as fixed carbon, converting CO_2 and water to sugars, $(CH_2O)_X$ as shown in equation 2.1:

$$CO_2 + H_2O + \text{sunlight} \rightarrow (CH_2O)_x + O_2 \qquad (2.1)$$

The sugars thus produced are stored in three different types of polymers: cellulose, hemicellulose and starch. Biomass is typically composed of 65–85% sugar polymers on weight basis (principally cellulose and hemicellulose), with another 10–25% on weight basis corresponding to lignin. Other biomass components that are generally present in minor amounts include triglycerides, sterols, alkaloids, resins, terpenes, terpenoids and waxes (often collectively referred to as lipids), as well as inorganic minerals. Together, cellulose, hemicellulose and lignin constitute lignocellulose, the fibrous material that forms the cell walls of plants and trees. The cellulose forms bundles of fibres that provide strength (Crocker and Andrews, 2010).

Lignocellulosic biomass is the botanical term used for biomass from woody or fibrous plant materials, being a combination of lignin, cellulose and hemicellulose polymers interlinked in a heterogeneous matrix (Robinson *et al.*, 2002 as cited in IEA, 2008).

The lignocellulosic materials are the most abundant organic compounds in the biosphere, participating in approximately 50% of the terrestrial biomass. The term lignocellulose structure is related to the part of the plant which forms the cellular wall (half-lamella, primary and secondary walls), composed of fibrous structures, basically constituted of polysaccharides [cellulose (40-60%) and hemicellulose (20-40%)]. These components are associated to a macromolecular structure containing aromatic substances, denominated lignin (15-25%) (Sun and Cheng, 2002 as cited by Pereira *et al.,* 2008). As stated above, the main components of lignocellulosic biomass are cellulose, hemicellulose and lignin.

2.1.5 ESTIMATION OF AGRICULTURAL CROP WASTE POTENTIAL

Accurate estimates of the availability of crop residues require good data on crop production by region or district. If these data are not available, a survey will be necessary. A survey should include information on all the uses for crop residues besides fuel (burning in situ, mulching, animal feed, house building, etc.) so that the amount available as fuel can be calculated. Crop residues are usually derived from parts of the plant growing above ground. Exceptions include groundnuts and sometimes part of cotton crop residues (Rosillo-Calle *et al.,* 2007).

Agricultural crops are grown either commercially or for subsistence. To obtain accurate estimates of residues production, it is therefore important to have good estimates of crop production by country, region or district. This may entail undertaking surveys, especially in the subsistence sector to determine production of both crops and plant residues, and should include all possible uses of residues in addition to fuel. It is likely that little or no information will be available for subsistence crops, so it will be necessary to collect data, possibly using remote sensing techniques. Total production can then be calculated using existing data on the yields of the various crops. The quantity of residues can be calculated via estimates of the ratio of by-product to main crop yields for each crop type and the relation between crop and by-product, and by multiplying the crop production of a particular year by the residue ratio, i.e. in the case of wheat 1.3 times as much wheat straw is produced compared to the grain yield, depending on the variety.

Another method for estimating crop residues is to use the crop residue index (CRI). This is defined as the ratio of the dry weight of the residue produced to the total primary crop produced for a particular species or cultivar. The CRI is determined in the field for each crop and crop variety, and for each agro-ecological region under consideration. It is very important to state clearly whether the crop is in the processed or unprocessed state. Residue production is estimated according to equation 2.2 as defined by Lal (2005).

$$Residue\,production = grain\,production \times \frac{straw}{grain} \qquad (2.2)$$

2.1.6 Residue to Product Ratio (RPR) of Agricultural Crops

The yield of the crops has a definite relationship with the residue that is left after extracting the produce. The RPR is defined as the gravimetric ratio of the residue to the actual produce of the crop. The near accuracy of the RPR value of a particular crop leads to the realistic estimates of the total residue generated (Murali *et al.*, 2008).

According to Esteban *et al.* (2008), RPR can be obtained in the following different ways:

- Sampling a crop before harvest: this consists of weighing the total crop biomass in sample plots just before harvesting. Samples are collected in each plot and carried to the laboratory where grain is separated from straw and weighed. The fractions are oven dried to estimate moisture content.

- Sampling residue after grain harvest: this procedure consists of weighing and sampling the residue that lies on the floor, usually in rows, after harvest. A portion of each residue row is weighed. Average row length and the distances between row axes have to be recorded. Samples are taken for oven drying.
- Evaluating straw production in a parcel: this procedure is similar to procedure 2, but in this case the residue is harvested completely and the whole parcel is weighed.

2.1.6.1 RPR of Maize Residues

a) **Maize Stalks:** The literature shows widely varying RPR values ranging from 1.0 to 4.328 (Koopmans and Koppejan, 1997). The RPR values of maize stalks reported by Osei (2013), Esteban *et al.* (2008), Murali *et al.* (2008), OECD/IEA (2010) and Maithel (2009) were 1.43 (at a moisture content of 71.1%), 1.0-4.33, 1.2-1.7 (at a moisture content of 30%), 1.61 (at a moisture content of 10%-12%), 1.5 (at a moisture content of 15%) and 1.0-2.5 respectively. A value range of 1.0 -2.0 has been reported in the literature by Koopmans and Koppejan (1998).

b) **Maize husks:** Biopact (2006), Osei (2013) and Maithel (2009) have reported a value of 0.2-1.8, 0.23 (at a moisture content of 26.8%), and 0.2 respectively.

c) **Maize Cobs:** An RPR of 0.22 (at a moisture content of 45.38%), 0.2-1.0 and 0.18-0.27 for maize cobs have been reported by Osei (2013), Biopact (2006) and Maithel (2009) respectively.

2.1.6.2 RPR of Sorghum Residues

OECD/IEA (2010), Esteban *et al.* (2008), Murali *et al.* (2008) and Biopact (2009) reported an RPR of sorghum stalks to be 2.62 (at a moisture content of 15%), 1.5-2 (at a moisture content of 20%, 1.4 (at a moisture content of 10-12%) and 0.9-7.4 respectively whereas Barnard and Kristofferson (1985) and Koopmans and Koppejan (1998) gave an RPR of sorghum stalks ranging from 2.0-4.6 and 1.25-4.0 respectively.

2.1.6.3 RPR of Millet Residues

The RPR of millet stalks was given by Maithel (2009), Biopact (2006), Murali *et al*. (2008), OECD/IEA (2010) as 2.0-3.7, 1.1-2, 1.4 (at a moisture content of 10-12% and 3.00 (at a moisture content of 15%) respectively while Barnard and Kristofferson (1985) and Koopmans and Koppejan (1998) reported an RPR of millet stalks to range from 2.0-4.6 and 2.0-4.0 respectively.

2.1.6.4 RPR of Groundnut Residues

An RPR of 2.3 (at moisture content of 10-12%), 2.5 (at moisture content of 15%), 2.29-2.9 and 2.3-2.9 was indicated for groundnut straws by Murali *et al.* (2008), OECD/IEA (2010), Biopact (2006) and Maithel (2009) respectively. Barnard and

Kristofferson (1985) and World Bank (Guinea, 1986; Mali, 1991; and Senegal, 1983) as cited in Yevich and Logan (2002) reported an RPR of groundnut shells as 0.5 and 0.25-0.5 respectively.

2.2 FUNDAMENTAL CONCEPTS OF BIOFUELS

2.2.1 GENERAL OVERVIEW OF BIOFUELS

Mankind has, for most of its existence, relied on renewable energy resources like wood, windmills, water wheels and animals such as horses and oxen. The development of new energy resources was a major driving force of the technological revolution. Early in the nineteenth century, alcohols were repeatedly reported as biofuels. Even the invention of ignition engines was done with biofuels. Nikolaus August Otto developed his prototype of a spark ignition engine in the 1860s using ethanol and was sponsored by the sugar factory of Eugen Langen who was interested in the mass production of ethanol. Deutz Gas Engine Works designed one third of their heavy locomotives to run on pure ethanol in 1902. Safety and cleanness were contributing factors for that. Ethanol was soon recognised as an anti-knocking additive for internal combustion engines and was added to gasoline between 1925 and 1945. The ethanol present in the fuel allowed higher piston compression, increasing engine efficiency (Antoni *et al.*, 2007).

The story about diesel engine began in 1893, when Rudolph Diesel published a paper entitled "The theory and construction of a rational heat engine". The paper described a revolutionary engine run on vegetable oil (Demirbas, 2008) as cited in Fink (2010).

During the years of the Great Depression, the American farm economy was in dire straits. Prices were low, and farmers were going bankrupt at unprecedented rate. There was a great public outcry for the federal government to do something about the situation. This attracted the attention of researchers who started a movement that became known as “chemurgy,” which focused on the conversion of natural commodities to new and useful materials. This techno-political movement resulted in the formation of the National Farm Chemurgic Council (NFCC) in the mid-1930s led by Henry Ford, a proponent of products like corn-derived ethanol fuels and soybean-based plastics (Cote and Finkenstadt, 2008). Henry Ford designed the Model T car which ran on 100% bioethanol (Kovarik, 1998) as cited in Antoni *et al*. (2007).

With the exploration of huge supplies of crude oil in the 1940, ethanol production was widely abolished due to the unbeatably low price of petroleum prices particularly in the USA. However, during the World War II, shortages of petroleum fuels led to the demand of biofuels and hence their use as alternative fuels (Antoni *et al.*, 2007).

2.2.2 DEFINITION OF BIOFUELS

According to IEA (2011), biofuel refers to liquid and gaseous fuels produced from biomass – organic matter derived from plants or animals.

The Dictionary of Energy defines biofuels as any solid, gaseous or liquid fuel obtained from biomass (Cleveland and Morris, 2006) as cited in Smith (2008).

Biofuels are fuels produced from renewable resources, especially plant biomass, vegetable oils, and treated municipal and industrial wastes. Biofuels are considered neutral with respect to the emission of carbon dioxide because the carbon dioxide given off by burning them is balanced by the carbon dioxide absorbed by the plants that are grown to produce them (Free online Dictionary, 2013).

Biofuel is any fuel that is derived from biomass, recently living organisms or their metabolic byproducts, such as manure from cows. It is a renewable energy source, unlike other natural resources such as petroleum, coal and nuclear fuels (Arumugam *et al.*, 2007).

2.2.3 CLASSIFICATION OF BIOFUELS

According to International Resource Group (IRG) (2009), biofuels are categorized into first-generation biofuels and advanced biofuels (second generation and third-generation).

2.2.3.1 FIRST-GENERATION BIOFUELS

The term first-generation biofuels generally refers to fuels produced from agricultural crops grown for food and feed, and from new oilseed crops such as jatropha and pongamia. The technologies to produce these fuels are well developed and widely used. Currently, the most common forms of first generation biofuels are ethanol (an alcohol) derived from grains or sugarcane, and biodiesel (an ester) derived from oils or fats (International Resource Group, 2009).

The most common types of biofuels are ethanol, biodiesel and biogas (Arumugam *et al.*, 2007).

2.2.3.2 BIOETHANOL

Ethanol is currently produced from sugar crops (sugarcane, sugar beet, sweet sorghum) or starchy crops (corn, wheat, cassava) through a process of fermentation and then distillation, employing first generation technology. The basic production process of ethanol from both types of crop is similar. However, the energy requirement for starch-based ethanol is significantly more than that of sugar-based ethanol due to the additional process involved in converting starches into sugar. Energy and greenhouse gas balances are, therefore, more favourable for ethanol production from sugar crops than from starch crops (Mandil and Shihab-Eldin, 2010).

Bioethanol production processes from sugar or starch crops are the most traditional and developed pathways. According to Chiaramonti (2007) as cited by Fink (2010), fermentation is performed by microorganisms in the absence of oxygen according to the following main reaction:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO \quad (2.3)$$

Ethanol (ethyl alcohol) has long been recognized as a fuel suitable for a variety of applications, including transportation and cooking. Ethanol can be used in stoves adapted for its use for cooking. It can be further processed to add a thickening agent, water and colouring to create a combustible ethanol gel that is safe, non-toxic, non-spill and potable. This gel has been successfully tried as cooking fuel with private sector plants in various Southern African countries (Utria, 2004) as cited by Zuzarte (2007).

Ethanol (either straight or jellified) can also be used in households for cooking as a substitute for wood, charcoal or kerosene and for lighting as a substitute for kerosene. Gelfuel is currently being distributed in several countries in Africa as a fuel for cooking. Gelfuel has several advantages compared to straight ethanol: one cannot drink it, it is easier and less dangerous to store and transport, and it is less likely to have fire in the household because if the stove falls the burning gel does not spread (Legoupil and Ruf (n.d). Ethanol can be used in blends of up to 10% in conventional spark ignition engines or in blends of up to 100% in modified engines (Mandil and Shihab-Eldin, 2010).

2.2.3.3 BIODIESEL

In a broad sense, biodiesel refers to pure and processed plant oils or animal fats. These oils and fats contain a mixture of triglycerides, free fatty acids, phospholipids, sterols, water, odorants and other impurities. Biodiesels are nowadays produced from a large range of oilseed crops, mainly rapeseed or canola, soybean and sunflower, palm oil and jatropha curcas in tropical climates. Other potential oil plant feedstock includes mustard seed, linseed, castor oil, peanut, cottonseed, coconut, lesquerella or micro-algae. The most widespread biodiesels are methyl esters produced from plant oils combined with methanol through transesterification (Bessou, 2009).

2.2.3.4 BIOGAS

Biogas can be produced through anaerobic digestion of feedstocks such as organic waste, animal manure and sewage sludge, or from dedicated green energy crops such as maize, grass and crop wheat. Biogas is often used to generate heat and electricity, but it can be also upgraded to biomethane by removing CO_2 and hydrogen sulfide (H_2S), and injected into the natural gas grid. Biomethane can also be used as fuel in natural gas vehicles (IEA, 2011).

2.2.3.5 FOOD VERSUS FIRST GENERATION BIOFUEL DEBATE

The use of potential food crops as feedstocks for first generation biofuels has sparked debate about its sustainability. The main areas of the biofuels debate include food price increases, land competition and greenhouse gas/environmental issues. Basically, there are two main schools of thought: the anti-biofuels lobby and the pro-biofuels lobby (Rosillo-Calle, 2012).

The "anti-biofuels" lobbyists argued that, it is morally wrong to use land to produce biofuels instead of food. They assert that large scale production of biofuels will lead to food insecurity worldwide thereby increasing food prices which will disproportionately affect the poorest people in developing countries. They maintain that land competition will increase with demand for land to grow crops for food and that for biofuels leading to deforestation, ecosystem destruction, and loss of biodiversity and soil erosion (Rosillo-Calle, 2012).

On the contrary, the "pro-biofuels" argue that there is sufficient land available to produce both food and a reasonable portion of biofuels (i.e., 5–20% of transport fuels demand) without affecting food supply, with good and modern agricultural management practices. Proponents of biofuels maintain that food insecure countries that do not have their own fossil fuel reserves allocate a significant portion of their national income to pay for oil imports. In such cases, biofuels are a good alternative to fossil fuels and would free up foreign exchange for other investments (Rosillo-Calle, 2012).

2.2.4 SECOND -GENERATION BIOFUELS

Second generation or lignocellulosic biofuels are derived from feed stocks not traditionally used for human consumption. As a result, there is much less concern about the use of these fuels leading to famine in developing countries, or adversely affecting consumer prices in developed nations (Maxwell, 2009; Demirbas et al., 2009) as cited in Fink (2010).

According to a UN report on biofuels, "2nd-generation biofuels are made from lignocellulosic biomass feedstock using advanced technical processes". Lignocellulosic sources include "woody", "carbonaceous" materials that do not compete with food production, such as leaves, tree bark, straw or woodchips (Patumsawad, 2011).

Second generation biofuels are in contrast to the first generation biofuels because they are not made out of food crops. These fuels are being extracted from waste biomass, stems and leaves, sewage sludge and energy crops. The advantage of the second generation biofuels is the fact that the food verses fuel debate is not fully applicable (Dubbelboer, 2009).

There is the belief that 2nd-generation biofuels are more promising than their 1st-generation counterparts because they have a more favourable green gas balance. Cellulose ethanol could produce 75% less CO_2 than normal gasoline, whereas corn, cassava or sugarcane ethanol reduces CO_2 levels by just 60%. Furthermore, they are able to use a wider range of biomass feedstocks, and do not compete with food production and they could use less land (Patumsawad, 2011).

2.2.5 THIRD GENERATION BIOFUELS

Third generation biofuels are made from algae and bacteria. Oil producing algae are grown in ponds and harvested. The oil is extracted out of the algae and upgraded to biodiesel (New Scientist, 2007) as cited by Dubbelboer (2009).

Third-generation biofuels are obtained from feedstock with better sustainability properties than second- generation biofuels. Currently, the most promising feedstocks come from microalgae and photosynthetic microorganisms of less than 0.4 mm in diameter that use sunlight, water, and carbon dioxide to produce algal biomass (Chisti, 2008) as cited by International Resource Group (2009). According to the Author, algae can grow in ponds or photo bioreactors, or in hybrid systems that combine the two approaches, thus avoiding the need to use arable land.

2.2.6 BIOFUEL CONVERSION ROUTES

The production of biofuels from lignocellulosic feedstocks can be achieved through two very different processing routes namely biochemical and thermochemical (Patumsawad, 2011).

2.2.6.1 Biochemical conversion of lignocellulosic biomass to ethanol

Biochemical conversion uses biological agents, specifically enzymes or microorganisms, to carry out a structured deconstruction of the lignocellulose into its polymers and to further break down cellulose and hemicellulose into monomeric sugars including glucose and xylose (IEA, 2008).

Ethanol can be produced from lignocelluloses biomass by hydrolysis and sugar fermentation processes. In order to produce sugars from the biomass, the biomass is pre-treated to reduce the size of the feedstock and to open up the plant structure. The cellulose and the hemicelluloses portions are broken down (hydrolysed) by enzymes or dilute acids into glucose or sucrose sugars and then fermented into ethanol (Idi and Mohamad, 2011).

The conversion of biomass to fuel includes the hydrolysis of various components in the lignocellulosic materials to fermentable reducing sugars and the fermentation of the sugars to fuels such as ethanol and butanol. The pretreatment step is mainly required for efficient hydrolysis of cellulose to its constituent sugars. The hydrolysis is usually catalyzed by acids or cellulase enzymes, and the fermentation is carried out by yeasts or bacteria (Kumar *et al., 2009*).

The biochemical conversion of lignocellulosic feedstock to ethanol involves four main steps: pretreatment, hydrolysis, fermentation, and product separation/purification (Mosier *et al*., 2005) as cited by Zhang (2010).

2.2.6.1.1 Pretreatment of lignocellulosic biomass

Pretreatment refers to the solubilisation and separation of one or more components of the biomass (hemicelluloses, cellulose, and lignin) to make the remaining solid biomass more accessible to further chemical or biological treatment. This is a main processing challenge in the production of ethanol from lignocelluloses biomass. The goal of pre-treatment is to remove lignin and hemicelluloses, reduce cellulose crystallinity and increase the porosity of the biomass (Sun and Cheng, 2002) as cited by (Idi and Mohamad, 2011).

Pretreatment is required to alter the biomass macroscopic and microscopic size and structure as well as its submicroscopic structural and chemical composition to facilitate rapid and efficient hydrolysis of carbohydrates to fermentable sugars (Chang and Holtzapple, 2000) as cited by Zheng *et al*. (2009).

The pretreatment stage is mainly used to disrupt the structure of lignocellulose in order to make it vulnerable for hydrolysis by enzymes or other hydrolyzing agents. In addition, pretreatments may also be able to partially separate the lignin from the rest of the lignocellulose and partially hydrolyze the hemicellulose to oligomers or monomers.

The main aim of pretreatment is to alter the structure of lignocellulose, improving accessibility and reactivity of the cellulose, while partially separating it from lignin and hemicellulose (Shen, 2012).

A generalized classification of pretreatment methods groups them into: physical, chemical, biological and multiple or combinatorial pretreatment. In combinatorial pretreatment methods, physical parameters such as temperature or pressure or a biological step are combined with chemical treatments and are termed physicochemical or biochemical pretreatment methods (Agbor *et al*., 2011).

2.2.6.1.2 Hydrolysis

After pretreatment is over, the cellulose is prepared for hydrolysis. Hydrolysis is the depolymerization of the cellulose and hemicelluloses in the plant cell walls to monomeric sugars, which can then be fermented to produce ethanol. This is achieved by adding a water molecule as shown in the reaction below (Rajvanshi, 2010):

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6 \qquad (2.4)$$

Zheng *et al*. (2009) gave an explanation of hydrolysis as the processes that convert the polysaccharides into monomeric sugars. The fermentable sugars obtained from hydrolysis process could be fermented into ethanol by ethanol producing microorganisms, which can be either naturally occurring or genetically modified.

According to Organisation of American States (OAS)/Department of Sustainable Development (DSD) (2009), hydrolysis is the process where long chains of sugar molecules that have cellulose molecules are broken down to free the sugar before it is fermented for alcohol production. The hydrolysis (Cellulolytic) processes most commonly used are the chemical reaction using acids or an enzymatic reaction.

Enzymatic Hydrolysis

This uses enzymes, biological catalysts, to break down the cellulose polymers into monomeric sugars. The enzymatic hydrolysis reaction is carried out by means of enzymes that act as catalysts to break the glycosidic bonds (Demers *et al.*, 2009). The use of enzymes is necessary as these are highly specific biocatalysts which can potentially give near quantitative yields of products without further degradation or any-product formation. However, the structure of lignocellulosic biomass is very complex and needs to be broken down to a certain extent for the enzymes to be able to access cellulose chains and depolymerize them (Jeoh *et al.*, 2007 and Donohoe *et al.*, 2009) as cited in Kothari (2012). Thus enzymes are used in combination with pretreatment of biomass to give sugars which are further converted into ethanol by various microorganisms.

The cellulase consists of three consortiums of enzymes:

- Endoglucanase (example, endo-1,4-D-glucanohydrolase) which attacks regions of low crystallinity in the cellulose fiber, creating free chain-ends,
- Exoglucanase or cellobiohydrolase, which degrades the molecule further by removing cellobiose units from the free chain-ends and

- Glucosidase (cellobiase) which hydrolyzes cellobiose to produce glucose. Coughlan and Ljungdahl (1988) as cited in Idi and Mohamad (2011). These are usually derived from the fungus *Trichoderma reesei*.

2.2.6.1.3 Fermentation

Fermentation is a process that uses yeast to break down sugar molecules into carbon dioxide gas and ethanol (ethyl alcohol). Fermentation begins as the growing population of microorganisms produces enzymes to break two-molecule sugars into single molecule sugars (if needed or capable), and then convert the single molecule sugars into the commercial chemicals and byproducts. Yields of chemicals approach a limit as the microorganisms either consume all the fermentable sugars or the products and byproducts of fermentation inhibit (or kill off) the organism (Idi and Mohamad, 2011).

For many years, the traditional brewery industry used the *Saccharomyces cerevisiae* yeast of the fungi kingdom to produce ethanol from *hexoses (6-carbon sugar)* but this kind of yeast does not work with more complex structure present in the biomass feedstock impeding the complete use of material available to produce ethanol. For example, only about 50-60% of the sugar derived from cellulose-rich plant materials is glucose. The remaining 40-50% is largely a sugar called "xylose," which naturally occurring yeast cannot ferment to ethanol (OAS/DSD, 2009).

In recent years, metabolic engineering concepts have been used for the production of fuel ethanol. Ethanologenic recombinant bacteria such as *Escherichia coli*, *Klebsiella oxytoca*, and *Zymomonas mobilis* and the yeast *Saccharomyces cerevisiae* were successfully used in fermentation of mixed sugars obtained from biomass containing glucose, xylose, arabinose, and galactose to produce ethanol. The genetically engineered microbes *Zymomonas mobilis* AX101, *Escherichia coli* KO11, *Klebsiella oxytoca* P2, and *Saccharomyces cerevisiae* are considered for commercial scale-up (Jeffries and Jin, 2004; Bothast *et al.*, 1999 and Dien *et al.*, 2003) as cited by Kumar *et al.* (2009).

2.2.6.1.4 Ethanol Recovery/Purification/Separation

Ethanol can be purified by distillation to a concentration just below its azeotropic point, i.e. 95%, which will be called 'hydrated ethanol' (Hamelinck *et al.*, 2005) as cited by Taherzadeh and Karim (2007). According to Taherzadeh and Karim (2007), hydrated ethanol can be employed in high-ethanol-content fuel (e.g. E95). The author stated that for ethanol to be mixed with gasoline, the ethanol should contain no more than 1% of water (anhydrous ethanol). Anhydrous Ethanol (high purity) ethanol can be produced by employing methods such as dehydration, azeotropic distillation, extractive distillation and so on (Kumar *et al.*, 2010).

The oldest method of producing anhydrous ethanol is the dehydration with quicklime. This process is still used on a laboratory scale. In this process, water is removed by a chemical reaction. Quicklime (calcium oxide) reacts with water to form calcium hydroxide. In this process, the ethanol–water solution is mixed with quicklime in a ratio of about 4.2 kg (or more) of lime for each kg of water to be removed (as determined with a hydrometer) and allowed to ‘‘slake’’ for 12–24 h with occasional stirring. The lime reacts with the water to form calcium hydroxide. The calcium hydroxide is insoluble in the ethanol and so the relatively pure (99.5 wt.%) ethanol goes to the top of the container and the calcium hydroxide settles to the bottom. The usual method of separating the lime and calcium hydroxide from the ethanol is by distillation (Kumar *et al.*, 2010).

2.2.7 NET ENERGY BALANCE OF SECOND GENERATION BIOFUELS

The net energy balancing (NEB) method is often used to make energy-efficiency comparisons between fuels. The fuel with the higher NEB is said to be more energy efficient (Shapouri *et al.*, 2006). The net energy balance of a system compares the amount of useful energy derived (output) to the system energy inputs (Denholm and Kulcinski, 2003). The net energy gain (net energy balance) is defined as the difference between the energy in the fuel product (output energy) and the energy needed to produce the product (input energy) (Andress, 2002).

The net energy value is used to determine if more fossil energy is consumed during the production of a biofuel than is produced by the biofuel itself. The net energy value is often used to evaluate the energy benefits of ethanol production (Groode and Heywood, 2008). The net energy value has been defined and calculated in different ways by different authors. Groode and Heywood (2008) defined the net energy value by subtracting the input fossil fuel energy from the output biofuel energy (Rajvanshi, 2010). The output biofuel energy is also called gross energy.

According to Groode and Heywood (2008), Net energy value is defined according to equation 2.5

$$NEV \left(\frac{MJ}{L} ethanol\right)$$

$$= Output\ biofuel\ energy \left(\frac{MJ}{L}\ ethanol\right) - \sum Fossil\ input\ energy \left(\frac{MJ}{L}\ ethanol\right) \quad (2.5)$$

The *Output Energy* is defined as the lower heating value of ethanol which is 21.2 MJ/L.

Other authors (De Oliveira *et al*., 2005; Evans and Cohen, 2009) have presented a ratio of output energy of biofuel to input energy of fossil fuels (Rajvanshi, 2010) as stated in equation 2.6. That is

$$Net\ energy\ ratio = \frac{(Output\ energy\ of\ biofuel\ bases\ on\ lower\ heating\ value)}{(input\ energy\ of\ fossil\ fuel)} \quad (2.6)$$

Many have also included labor energy converted from hours to joules in the input in addition to the fossil fuels (Rajvanshi, 2010).

The fossil fuel has energy balance between 0.8 and 0.9. In other words, it requires 1.2MJ of energy to produce 1.0MJ of fossil fuel (petrol or diesel). For biofuels to offer advantage over fossil fuels, they must have a net energy ratio greater than one (Rutz and Janssen, 2007 and IRG, 2009).

The energy output/input ratio ('net energy ratio') is used as an indicator of energy efficiency (De Vries, 2012). According to De Vries (2012), the net energy is calculated using equation 2.7:

$$E_{net} = E_{gross} - E_{fert} - E_{pest} - E_{diesel} - E_{transport} - E_{conv} \quad (2.7)$$

E_{net} = net energy yield (MJ)

E_{gross} = gross energy yield from biofuel (MJ)

E_{fert} = the energy requirements for producing/manufacturing fertiliser (MJ)

E_{pest} = the energy requirements for producing/manufacturing biocides (MJ)

E_{diesel} = the (diesel) energy consumed by farm machinery during farm operation

$E_{transport}$ = the energy (diesel) required for transporting the feedstock to conversion facility, transporting fertiliser to farms and distributing biofuels produced to filling stations (MJ)

E_{conv} = the energy required for converting the feedstock into biofuel (MJ)

Luo *et al*. (2009) estimated the net energy ratio of corn Stover to be 1.5 whilst Wang (2001) determined the net ratio of corn Stover to be 2.1. Furthermore, Adusumilli *et al*. (2013) estimated the net energy ratios for both Switch grass and Sorghum which were

3.96 and 3.32 respectively. Table 2.1 shows the net energy ratios of first and second generation feedstocks cited from the literature.

Table 2.1: Net energy ratios of first and second generation feedstocks

Feedstock	Net energy ratio	References
Sugar cane	0.9-1.8	Hopkinson and Day (1980)
	3.14-3.87	De Oliveira *et al.* (2005)
Corn with or without stover	1.4-2.23	Vadas *et al.* (2008)
Switchgrass	10.36-11.31	Vadas *et al.* (2008)
	13.1	Schmer *et al.* (2008)
Alfalfa-Corn	2.87-3.05	Vadas *et al.* (2008)
Sweet sorghum	0.9-1.1	Worley *et al*. (1992)

Source: Rajvanshi (2010)

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 INTRODUCTION

This study assessed the potential of lignocellulosic agricultural crop waste biomass (residues) for the production of second generation biofuels in the Lawra district. The methodology used in this study varied depending on the specific objective stated in this thesis. For the purpose of this research, both primary and secondary data sources were employed. Methods used in this study included: site visits, interviews, survey, field and laboratory experiment. The analytical tool used in this study was from the Microsoft Excel spreadsheet. Below is a brief description of how each objective was achieved (that is methods and the type of data sources used).

3.1 The Study Area

The Lawra-Nandom district is located in the Upper West Region of Ghana (see Figure 3.1). It is a principal food hub for the country. The total area of the district is 1051.2 square km with a 2010 population of 100,292 and a population growth rate of 1.7% (Ghana Statistical Service, 2012). The climate of the district is tropical continental type with the mean annual temperature ranging between 27°C to 36°C. The period between February and April is the hottest. The district lies within the Guinea Savannah Zone which is characterized by short grasses and few woody plants. Common trees in the district consist of drought and fire resistant trees such as *baobab, dawadawa, shea trees* and *acacia*. Agriculture accounts for 80% of the economy of the district. The major crops cultivated in the district include maize, millet, sorghum, cowpea, groundnuts and soybean. In the animal sector, production and rearing of livestock include cattle, sheep, goats, pigs and poultry (Lawra-Nandom District Assembly, 2013).

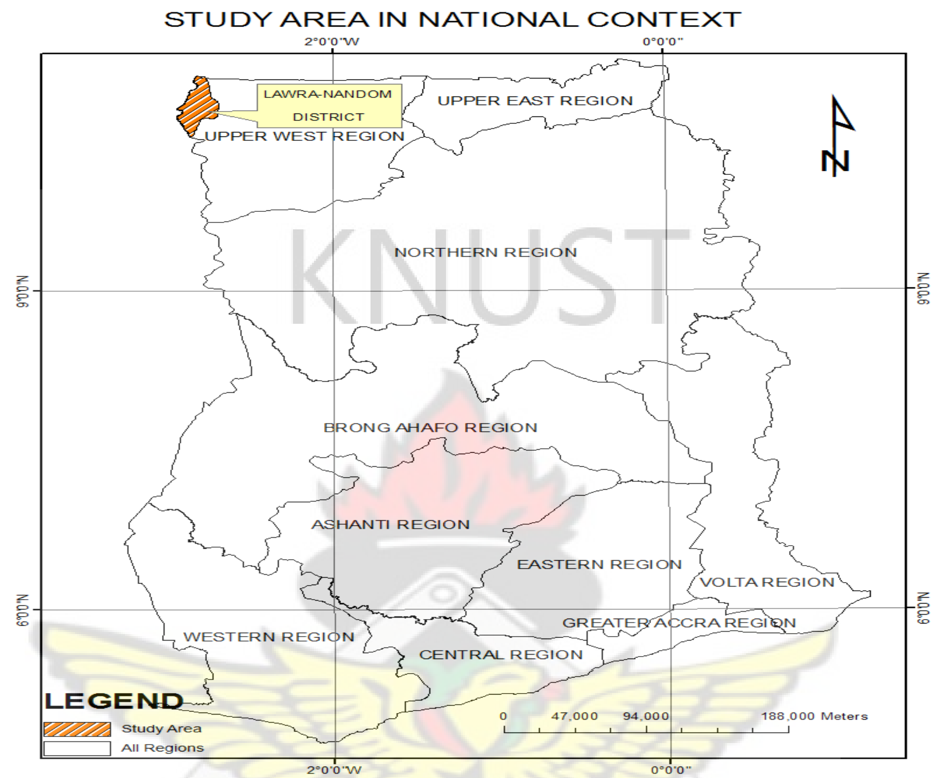

Fig.3.1: Map showing the studied area

3.2 Assessment of biomass residue and its ethanol potential in the Studied District

To assess agricultural crop waste biomass (residues) potential in the district, data on crop production as well as the residue-to-product ratio (RPR) of major crop types were collected. Data on crop production was obtained from the district office of the Ministry of Food and Agriculture (MOFA). RPR values were determined in the field and the moisture content of each crop residue was determined at the Savanna Agricultural Research Institute (SARI), which is located in the Upper West regional capital, Wa.

The following equipment/instruments were used for the field and laboratory experiment:

Electronic balance (Adam AFP-3100L), Electronic balance (Electro Samson), Hot oven, Pegs, Rope, Tape measuring, cutlass, Stopwatch and Bucket.

Procedure for RPR determination

The following procedure was used in the determination of RPR values:

1. Three farms each of maize, sorghum, millet and groundnut were selected randomly based on farmers' willingness to participate in the experiment.
2. Three plots each of size 10m by 10m were obtained by random sampling from each of the selected farms.
3. Crops from the plots were harvested and the weight of both the food products and the residue were recorded.
4. *RPR* of each residue type was determined using the weight of the food product and the residue (equation 3.1).

$$RPR = \frac{weight\ of\ residue\ from\ a\ food\ crop\ sample}{weight\ of\ the\ food\ crop\ sample} \qquad (3.1)$$

5. An average *RPR* was derived for each residue type.

Fig. 3.2: Harvesting sorghum residues

Fig.3.3: weighing sorghum residues

Fig.3.4: Weighing sorghum grains

Fig.3.5: Harvesting millet residues

Fig. 3.6: Weighing millet residues

Fig. 3.7: Weighing millet grains

Procedure for moisture content (MC) determination

The following procedure was followed in determining the MC of the samples:

1. A sample of fresh residues (W_w) in each plot was weighed in the field and taken to the laboratory for drying.
2. The fresh residues were dried in a hot box oven at 103ºC for 24 hours
3. The weight of the dried residues (*Wd*) was recorded.
4. The moisture content (*MC*) was determined using equation 3.2

$$MC = \frac{(W_w - W_d)}{W_w} \times 100\% \qquad (3.2)$$

It is generally accepted that not all residues will be available for bioenergy production due to their scattered nature, technical constraints (complexities of harvesting and transporting), ecosystem functions (maintenance of soil fertility and erosion protection), possibility of getting consumed by bush fires, and other uses (such as for animal fodder, domestic heating and cooking). A recoverability fraction of 10% to 25% of the total available residues has been assumed in previous studies (OECD/IEA, 2010) for energy purposes. IRG (2009) has suggested a recoverability fraction of 5%, 10% and 15% for biofuel production.

Groode and Heywood (2008) suggested an allowable removal rate of 30-50%. This study assumes 10%, 25% and 40% availability of residues representing low scenario, medium scenario and high scenario respectively.

To estimate the crop residue potential, the equation used by Lal (2005) and IRG (2009) were adopted and modified as shown in equation 3.3

$$W_B = \sum_i^{crop} CP_i \times RPR_i \times PR_i \tag{3.3}$$

where:

W_B = Weight of agricultural waste biomass (residues) produced (tonnes)

CP = Average crop production in (tonnes)

RPR = Residue-to-product ratio

PR = percentage of residue available for biofuel production

$\sum_i^{crop}$ = summation of all individual crop types

To estimate the ethanol production potential, equation 3.4 (Stark, 2007) was adopted.

$$V_{biofuel} = \frac{LHV_{bi} \times W_B}{LHV_{fuel} \times \rho_{fuel}} \times \eta_{production} \tag{3.4}$$

where:

$V_{biofuel}$ = volume of bioethanol production (litres)

W_B = amount of crop residue available (tonnes)

$\eta_{production}$ = thermodynamic conversion efficiency of bioethanol production

LHV_{fuel} = lower heating value of fuel (MJ/kg)

ρ_{fuel} = density of fuel (kg/l)

LHV_{bi} = lower heating value of particular crop biomass (MJ/kg)

The future residue potential was estimated by adopting the formula used by Mehta (2004) stated in equation 3.5.

By employing the method of regression analysis, the average annual growth rate (r) of crop production was estimated using crop production for the period 2003-2012 (see appendix D).

3.3 Estimation of Fuel Demand in the Studied District

One of the highlights of this study is to examine the possibility of replacing gasoline and cooking fuel demand with ethanol produced from crop residues. Whereas ethanol could be blended with gasoline to fuel internal combustion engines, it could also be transformed into ethanol gel fuels for cooking in rural communities. It was therefore necessary to estimate gasoline and cooking fuel consumption trends in the district.

Data on historic and present gasoline consumption was obtained from the oil marketing companies in the district. The demand for fuel was projected for 20 years (2013 to 2032) using equation 5 and 2012 as the base year. Using the gasoline demand growth rate from historic consumption, the formula used by Mehta (2004) was adopted as shown in Equation 3.5 to project future demand of gasoline. Three scenarios (low-growth, medium-growth and high-growth) were considered for gasoline demand projection. The low-growth scenario assumes that the demand for gasoline will increase at the rate of population growth in the district. The population growth rate in the district is estimated at 1.7% (Lawra District Assembly, 2013). Medium growth scenario assumed the national growth rate estimated for petroleum products demand (5.3%) by the Ministry of Energy (2010). The high-growth scenario assumes that the demand for gasoline will increase by approximately doubling the medium growth rate.

$$F_{fd} = C_{fd}\left(1 + \frac{r}{100}\right)^{n} \quad (3.5)$$

where:

F_{fd} = future (projected) fuel demand (litres)

C_{fd} = current fuel demand (litres)

n = projected number of years

r = growth rate

Woodfuel (firewood and charcoal) consumption was obtained by conducting household survey on woodfuel consumption. A sample size of 100 households was surveyed from the district. The sample size was determined using equation 3.6 (Israel, 2009)

$$n = \frac{N}{(1+N(e)^2)} \quad (3.6)$$

where:

n = sample size

e = margin of error which was taken as 10%

N = total number of households in the district = 18,158 based on 2013 estimates

A known quantity of new charcoal/firewood in each household was weighed and the household was made to cook their normal meals for a 24 hour period. On the next visit, the remaining charcoal/wood (unused) was weighed and a new sample weighed again for the next 24 hour period. The process was repeated for a 3 day period, covering a total of 72 hours. The actual amount of fuel used each day is obtained by subtracting the unused charcoal/wood from the new charcoal/wood supplied 24 hours earlier. The number of people in a household was used as basis to determine current per capita consumption of fuel.

To forecast the future traditional fuel demand in the district, the methodology and scenarios proposed by the IRG (2009) were adopted. Three scenarios were considered for traditional fuel demand. The low-growth scenario again assumes that the demand for traditional fuels will increase at the rate of district population growth of 1.7%. Medium growth rate assumed the national annual growth rate for woodfuel consumption of 2.79%. The high growth scenario assumed a doubling of growth rate for the medium growth scenario.

Fig.3.8: Weighing of charcoal at Eremon town (left) and firewood at Zambo town (right) in the Lawra district

3.4 Net Energy Balance Calculation

The net energy was calculated by adopting the equation used by De Vries (2012) and modified to suit the local condition. The net energy is calculated using equation 3.7:

$$E_{net} = E_{gross} - E_{fert} - E_{pest} - E_{diesel} - E_{transport} - E_{conv} \quad (3.7)$$

Where:

E_{net} = net energy yield (MJ)

E_{gross} = gross energy yield (MJ)

E_{fert} = the energy requirements for producing/manufacturing fertiliser (MJ)

E_{pest} = the energy requirements for producing/manufacturing biocides (MJ)

E_{diesel} = the (diesel) energy consumed by farm machinery during farm operation (MJ)

$E_{transport}$ = the energy (diesel) required for transporting the feedstock to conversion facility, transporting fertiliser to farms and distributing biofuels produced to filling stations (MJ)

E_{conv} = the energy required for converting the feedstock into biofuel (MJ)

For the computations in this study, equation 3.7 has been modified with the assumption that the feedstock source is crop residue which is considered as waste. Therefore the energy requirements for fertilizer, biocides and cultivation are allocated to the main crop grains and not the residues. However, energy required for harvesting ($E_{harvert}$) and collection of the residue ($E_{collection}$) were included.

Hence, equation 3.7 becomes:

$$E_{net} = E_{gross} - E_{harvest} - E_{collection} - E_{transport} - E_{conv} \quad (3.8)$$

Harvesting and collection were assumed to be done manually, in line with existing practices in the district. This creates jobs for rural households in the district. Manual energy expended for harvesting and collection of residues (measured in MJ) was determined using equation 3.9 (Chaudhary *et al.*, 2006).

$$E_{harvesting} + E_{collection} = 1.96 \times N_m \times T_m \quad (3.9)$$

Where:

N_m = Number of labourers per farm activity

T_m = Useful time spent by a labourer per farm activity (hours)

The average time taken by a labourer to harvest and collect residues was determined experimentally in the field. The collection of residues was also assumed to be done manually.

The energy required for transportation was determined using equation 3.10 developed by International Sustainability and Carbon Certification (2011).

$$E_{transport} = \frac{[\{d_{loaded} \times K_{loaded}\} + \{d_{empty} \times K_{empty}\}]}{M} \times LHV_{diesel} \qquad (3.10)$$

Where:

Transport distance, $d_{loaded/empty}$ *(km)* = The critical distance (**d_{Max}**) needed to be covered in order to transport the feedstocks from the various farms in the district to the plant site (return transports that are not taking place empty do not need to be taken into account) is given by Kumarappan (2011) in equation 3.11

$$\boldsymbol{d_{max}} = \left(\frac{Q}{\pi d_r}\right)^{0.5} \qquad (3.11)$$

Q = annual capacity of plant (tons)

$$dr = density\ of\ residues\ availability\ \left(\frac{tons}{Km^2}\right) = \frac{average\ residue\ availability}{total\ land\ area} \qquad (3.12)$$

K_{loaded} *(l/km)* = Fuel consumption of the respective mode of transport per km when loaded and

K_{empty} *(l/km)* = Fuel consumption of the respective mode of transport per km when empty.

M = mass of product being transported (tonnes)

LHV = Lower heating value of diesel (MJ/L)

3.5 Assessment of Financial Viability

Financial viability of ethanol production was assessed using Net Present Value (NPV) and Internal Rate of Return (IRR). The NPV and IRR were calculated according to Gittinger (1982) as stated in equation 3.13 and 3.14, respectively.

$$NPV = \sum_{t=0}^{N} \frac{(B_t - C_t)}{(1+r)^t} \tag{3.13}$$

where:

t = time of cash flow

N = life time of the biofuel plant

B_t = benefits (revenue) to be derived from sale of biofuels at time t

C_t = cost at time t,

r = discount rate (cost of borrowing)

Decision rule for NPV

(i) If NPV is positive, then the biofuel production is financially viable

(ii) If NPV is negative, then the biofuel production is not financially viable

IRR is the discount rate 'r' such that:

$$0 = \sum_{t=0}^{N} \frac{(B_t - C_t)}{(1+r)^t} \qquad (3.14)$$

The decision rule for IRR is as follows:

i) if IRR is greater than the cost of capital, the project is acceptable;

ii) if IRR is equal to the cost of capital, the investor is indifferent;

iii) If IRR is smaller than the cost of capital, the project should be rejected.

The data for the calculation of feedstock costs was collected through field observations and interviews with farmers and tractor operators. Data for other costs (investment costs, processing costs, repair and maintenance costs, etc) and revenues was obtained from the literature.

3.5.1 Cost Benefit Analysis

- **Cost Analysis**

The financial assessment of second generation biofuel production involves the operational costs, investment costs and revenues to be realised from the biofuel production. The operational costs consist of feedstock costs, processing costs, repairs and maintenance costs, utility costs and administrative costs. The investment costs include plant costs, land and building costs.

Feedstock costs

The feedstock costs include harvesting cost, collection cost and transportation cost. The formulae used for the calculation of the feedstock costs are taken from the Organization of American States (OAS)/

Sustainable Development (DSD) (2009).

a) **Harvesting cost**

The harvesting was manual following current trends. The harvesting cost (H_c) was estimated using equation 3.15.

$$H_c = \frac{R}{H_{cap}} \tag{3.15}$$

where

R = daily remuneration rate of labour (GH¢) per day, H_{cap} = harvesting capacity (t) per day

b) **Collection cost**

The residues were collected from different points on the farm before transported. The collection was also assumed to be done manually. The collection cost (C_c) was estimated using equation 3.16.

$$C_c = \frac{R}{C_{cap} * n} \tag{3.16}$$

where

R= daily wage (GH¢) per day, C_{cap} = carrying capacity of labourer (t), n = number of trips made by the labourer per day

c) **Transportation cost**

To estimate the transportation cost, a tractor with a trailer capacity of 10 tons is assumed to be used for the transportation of the crop residues from the farm to the plant site. The transportation cost (T_c) was estimated using equation 3.17.

$$Tc = \frac{d_{max} [(F_{cons} * C_{fuel} + R_d)}{(T_{cap} * S_t)} \qquad (3.17)$$

d_{max} = transportation distance, km

F_{cons} = fuel consumption of the tractor per hour of operation = 19.08L/h (DLG test Report 5435F, n.d)

C_{fuel} = the fuel cost = GH¢2.08/L (GBC, 2013)

R_d = driver's remuneration per hour, T_{cap} = carrying capacity of tractor = 10t

S_t = transportation speed of tractor in Km/h = 20Km/h

3.5.2 Revenue Analysis

The biofuel revenue/benefit = volume of biofuel x biofuel price

$$The\ net\ cash\ flow\ (benefit) = total\ revenue - total\ cost \quad (3.18)$$

The data for the calculation of feedstock costs was collected through field observations and interviews with farmers and tractor operators

Data for other costs (investment costs, processing costs, repair and maintenance costs, etc) and revenues was obtained from the literature.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Residue-to-product ratio and biomass availability

Residue-to-product ratio (RPR) and the moisture content (MC) of residues were determined for the four major crops in the Lawra district which are maize, sorghum, millet and groundnut. The average RPR and moisture content obtained for residues from these four crops are summarized in Table 4.1. Even though several factors could cause changes in these values in the future, the projection of residue availability assumes a fixed RPR for the projection years. The field determined RPR values are within the range of values reported by other researchers from locations outside Ghana but moisture contents obtained are higher, especially for the stalks, presupposing that harvesting is done in the district much earlier than elsewhere. The harvesting is done earlier so as to prevent the crops from being burnt by bush fires.

Table 4.1: Field determined RPR and MC of major crops in the Lawra-Nandom District

MAJOR CROP	RESIDUE TYPE	RPR	MOISTURE CONTENT (%)
MAIZE	Stalks	1.15	73.70
	Husks	0.23	62.16
	Cobs	0.57	14.51
SORGUM	Stalks	4.75	61.80
	Husks	0.14	2.74
MILLET	Stalks	5.53	63.57
	Husks	0.29	11.6
GROUNDNUTS	Stalks	1.73	18.86
	Shell	0.35	13.82

Source: Researcher’s values obtained from field and laboratory experiments (2014)

The field determined RPR for maize stalks in the studied district was 1.15 (at moisture content of 73.7%) which is lower than that found by Osei (2013), OCED/IEA (2010) and Murali *et al.* (2008) who reported an RPR of maize stalks as 1.43 (at a moisture content of 71.1%), 1.5 (at moisture content of 15%) and 1.61 (at a moisture content of 10-12%) respectively. However, the field determined RPR for maize stalks are within the ranges given by Biopact (2006), Esteban *et al.* (2008), Maithel (2009) and Barnard and Kristofferserson (1985) that reported RPR ranges of values of 1.0-4.33, 1.2-1.7 (at a moisture content of 30%), 1.0-2.5 and 1.2-2.5 respectively for maize stalks. The field determined RPR for maize husks is 0.23 (at moisture content of 61.16%) which is the same as the value of 0.23 reported by Osei (2013) and almost the same value of 0.2 as reported by Maithel (2009). Also, the value is within the range reported by Biopact (2006) which is 0.2-1.8. The field determined RPR of maize cobs is 0.57 (at a moisture content of 14.5%) which is higher than that given by Osei (2013) and Maithel (2009) who reported an RPR of maize cobs as 0.22 (at a moisture content of 45.38%) and 0.18-0.27 respectively. Also, the RPR for maize cobs found in the district is within the range given by Biopact (2006) which was 0.2-1.10. The higher RPR for corn cobs could be as a result of low yields, which could mean a much bigger cob relative to the maize kernels obtained.

RPR for sorghum stalks as determined from the field in the studied area was 4.75 (at a moisture content of 61.8%) which is far higher than that given by Murali *et al.* (2008) and OCED/IEA (2010) that indicated an RPR for sorghum stalks as 1.4 (at moisture content of 10-12%) and 2.62 (at a moisture content of 15%) respectively. However, the RPR for sorghum stalks from the field in the studied area are within the range given by Biopact (2006) that indicated an RPR of 0.9-7.4 for sorghum stalks and slightly higher than the range given by Barnard and Kristofferson (1985) and Koopmans and Koppejan (1997) that reported an RPR range of 2.0-4.6 and 1.25-4.0 for sorghum stalks. RPR for sorghum husks as determined from the field in the studied area was 0.14 (at a moisture content of 2.74%).

The RPR for millet residues as determined in the field was 5.53 at a moisture content of 63.67% which is far higher than that found by Biopact (2006) and Murali *et al.* (2008) that indicated an RPR of 1.1-1.2 and 1.4 at moisture content of 10-12% for millet stalks respectively. These values were slightly higher than that reported by OCED/IEA (2010), Maithel (2009), Barnard and Kristofferson (1985) and Koopmans and Koppejan (1997) who indicated an RPR value of 3 at moisture content of 15% and ranges of 2-3.7, 2-4.6 and 2.0-4.0 at a moisture of 15% respectively. The RPR for millet husks as determined from the field in the studied area was 0.29 at a moisture content of 11.6%.

It is worth noting that where RPR values are significantly higher than literature values particularly that of sorghum and millet stalks with corresponding higher moisture, the extra weight could be as a result of high moisture.

The RPR value of 1.73 (at a moisture content of 18.86%) was determined for groundnut straws which is lower than that indicated by Biopact (2006), Murali *et al.* (2008), OCED/IEA (2010) and Maithel (2009) who reported an RPR of 2.29-2.9, 2.3 at a moisture content of 10-12%, 2.5 at a moisture content of 15% and 2.3-2.9 respectively for groundnut straws. The RPR for groundnut shells was found to be 0.35 which is lower than that reported by Barnard and Kristofferson (1985) who indicated an RPR of 0.5 for groundnut shells but are within the range reported by Yevich and Logan (2002) that indicated an RPR range of 0.2-0.5.

The likely causes of variation of the residue to product ratio may be due to the following factors:

a) Uneven structure of the soil (some parts of the soil are well-structured and retains suitable moisture content and aeration whilst other parts of the soil are poorly-structured and does not retain suitable moisture content and aeration,
b) Uneven distribution of nutrients for crop use, and
c) Uneven spacing of the plant population (some parts of the plot are widely spaced whist others are closely spaced).

The average residue generated was estimated for each major crop using the average crop production for the period between 2003 and 2012 and the RPR determined. Sorghum generates the largest quantity of residues of about 160,410 tonnes annually and contributes 59% (by weight) of the total crop residues generated in the Lawra district. This is followed by millet which generates about 74,369 tonnes of residues annually or approximately 27% share of the total residues generated in the district. Groundnut and maize residues contribute just about 14% of potential residue available in the district (see details in Table 4.2).

Table 4.2: Estimation of crop residues availability

Crop type	Average Crop Production 2003-2012 (tonnes)	Residue type	Average residues generated (tonnes)	Total residues generated (tonnes)
Maize	2,802	Stalks Husks Cobs	3,222 644 1,597	5,463
Sorghum	32,804	Stalks Husks	155,818 4,593	160,410
Millet	12,778	Stalks Husks	70,663 3,706	74,369
Groundnut	15,176	Straws Shells	26,253 5,311	31,565
Total				**271,807**

Based on average crop production figures from 2003 to 2012, the district generates annually over 270,000 tonnes of residue which could be available for ethanol production. Due to reasons already described in preceding sections of this report, not all the residue generated will be available for ethanol production. Therefore, residue availability was estimated under three possible scenarios, thus: low, moderate and high use scenarios. The study assumes only 10% of residue available in the low scenario, 25% for the moderate scenario and 40% for the high scenario. Details of residue availability based on the three scenarios are presented in Table 4.3. In the low scenario, only 27,000 tonnes of residue is available for ethanol production with an increase to 109,000 tonnes in the high scenario.

Table 4.3: Estimated Amount of Residues Available for Biofuel Production in 2012

Crop type	Total average residue generated (tonnes)	Amount of residues available for biofuel production (tonnes)		
		Low Scenario (10%)	Medium Scenario (25%)	High Scenario (40%)
Maize	5,463	546	1,366	2,185
Sorghum	160,410	16,041	40,103	64,164
Millet	74,369	7,437	18,592	29,747
Groundnuts	31,565	3,157	7,891	12,626
Total	**271,807**	**27,181**	**67,952**	**108,723**

Following the process described in the methodology, future residues potential is projected for the low, medium and high scenario for a 20 year period, from 2013 to 2032. As shown in Figure 4.1, the residue generation in the district will reach 162,000 tonnes in the low scenario by 2032 and 650,000 in the high scenario.

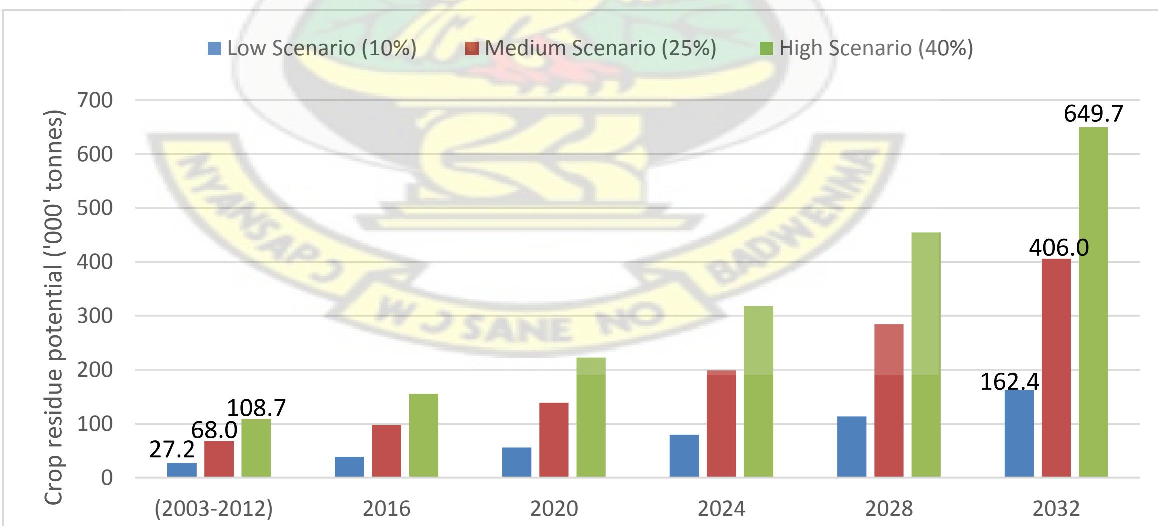

Figure 4.1: Projection of crop residue biomass potential from 2013 to 2032

4.2 Estimation of present and future ethanol production potential

Ethanol yield from crop residues is influenced by ethanol conversion rate or conversion efficiency. Groode and Heywood (2008) used cellulosic conversion efficiency of 67% in a study while De Vries (2012) assumed a conversion efficiency of 44% in another study. In this study, a cellulosic conversion efficiency of 44% was used with the assumption that the technology used will be at the lower end. The theoretical yield in litres per ton of the various crops is shown in Table 4.4. The total biofuel that could be produced under the low, medium and high scenarios are 9.397 million litres, 23.493 million litres and 37.588 million litres respectively. It is worth noting that sorghum residues will produce the highest quantity of biofuel in the district followed by millet. Even though groundnut residues have the highest theoretical ethanol yield, the district generates very little of those residues, hence ethanol potential is less than ethanol from sorghum and millet.

Table 4.4: Ethanol production potential in Lawra-Nandom District

Major Crops	**Theoretical Yield (L/t)**	**Ethanol production potential (million litres)**		
		Low Scenario (10%)	Medium Scenario (25%)	High Scenario (40%)
Maize	320.9004	0.175	0.438	0.701
Sorghum	352.41	5.653	14.132	22.612
Millet	321.5223	2.391	5.978	9.564
Groundnuts	373.14	1.177	2.945	4.711
Total		**9.397**	**23.493**	**37.588**

Ethanol production potential was projected into the future for 20 years, from 2013 to 2032. Figure 4.2 shows projected potential for ethanol from crop residues, up to the year 2032. The analysis reveals that in 2032 (20 years' time), the biofuel production potential in the district will increase from the 2012 potential of 9.4, 23.5, and 37.6 million litres under the low, medium and high scenarios respectively to 56.2, 140.4 and 224.6 million litres respectively.

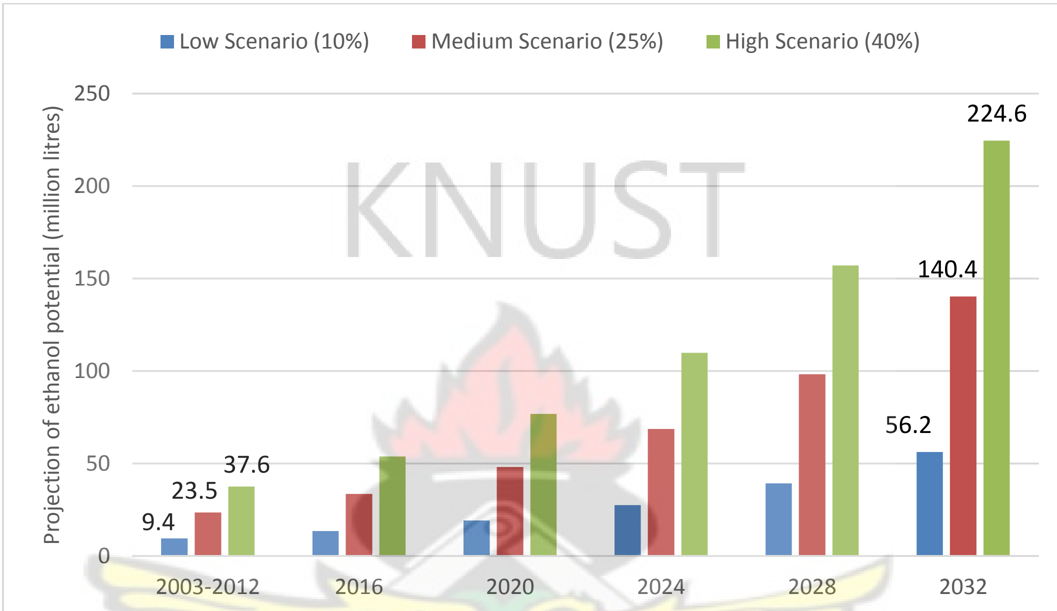

Figure 4.2: Projection of ethanol production potential from 2013 to 2032

In order to be able to compare the biofuel production potential with the total energy (gasoline and woodfuel) consumption in the district, the biofuel in litres was converted to energy values (tetrajoules) by multiplying by 21.2 MJ/L (i.e LHV of bioethanol) and projected to 2032 as shown in Fig.4.3.

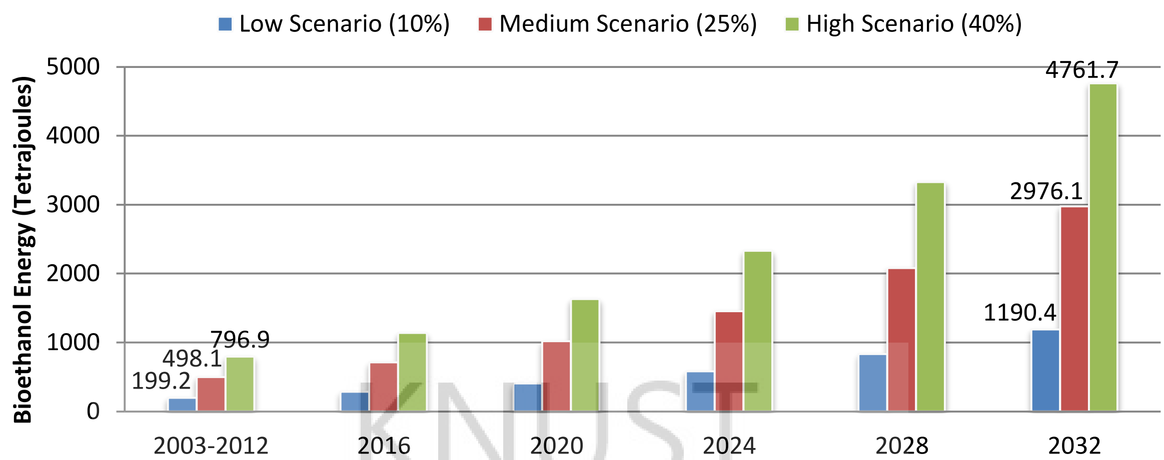

Fig.4.3: Projection of Bioethanol Energy Production from 2013 to 2032

4.3 Estimation of fuel demand in the district

Gasoline for transport and woodfuel (charcoal and firewood for cooking and heating) were considered as fuels in this research because of the potential for ethanol to replace these fuels using appropriate technology. Ethanol can be blended with gasoline and used in conventional vehicles or used wholly in new flexi-fuel vehicles (FFVs). With regards to cooking fuels, ethanol can be converted to gel fuels and used to replace firewood and charcoal in stoves designed for the purpose. Annual data on gasoline consumption was obtained from the oil marketing companies in the district. A field survey on household woodfuel consumption was conducted to estimate annual woodfuel consumption in the district.

The future gasoline consumption was projected for three growth scenarios using gasoline consumption in 2012 as the baseline. The estimation of future gasoline consumption indicated that in 2032, gasoline consumption will increase by 40.2% from 2012 levels under the low-growth scenario and by 180.96% and 650.1% under the medium and high scenarios respectively as shown in Fig.4.4.

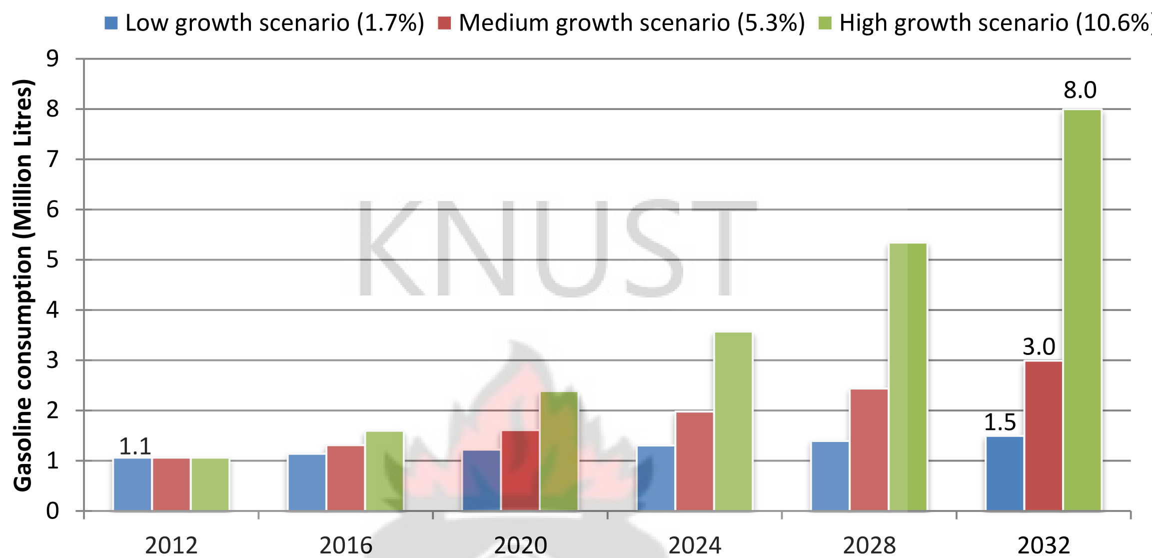

Fig.4.4: Projection of gasoline consumption from 2013 to 2032

The woodfuel consumption survey revealed that the average charcoal consumed by a household per day is 1.14 kg and the average firewood consumed by a household is 3.17 kg per day with details presented in Table 4.5.

Table 4.5: Summary of woodfuel consumption in the Lawra-Nandom district

Town	Average No. per Household	Charcoal consumption per household per day (kg)	Firewood consumption per household per day (kg)
Lawra	7	2.18	1.76
Zambo	6	0.26	4.44
Eremon	6	0.36	5.48
Nandom	5	1.76	1.01
Average for district	**6**	**1.14**	**3.17**

The number of households in the district is 18,158 according to data from the Ghana Statistical Service. Therefore, the total annual woodfuel demand in 2012 was estimated to be approximately 29,000 tonnes. The projection of future woodfuel consumption shows that in 2032, woodfuel consumption will increase between 40.2% and 150.1% over the 2012 consumption for low and high demand scenarios respectively as shown in Fig. 4.5.

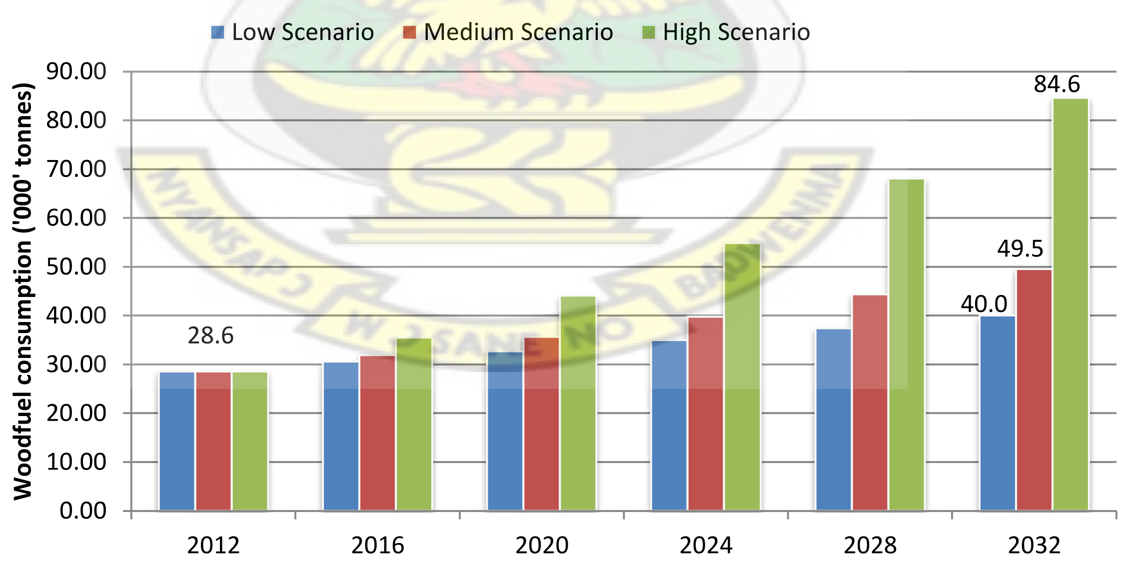

Fig.4.5: Projection of woodfuel consumption from 2013 to 2032

To ascertain the total amount of energy consumption (both gasoline and woodfuel), a common unit (Tetra Joules, TJ) was chosen and all values relating to gasoline (Litres) and woodfuel (tonnes) were converted to tetra joules (TJ) by multiplying by LHV of each fuel as shown in Table 4.6.

Table 4.6: Total energy consumption (both gasoline and woodfuel)

Fuel	Quantity	LHV	Energy (TJ)
Charcoal	7,555.54 t	33.00MJ/Kg	249.33
Firewood	21,009.71 t	16.00MJ/Kg	336.16
Petrol	1,066,000.00 L	32.6MJ/L	34.75
Total			**620.24**

The total energy consumed annually in the district is 620.24TJ. The projection of energy consumption in the district suggests that in 2032, the energy consumption in the district will increase between 40.2% and 221.7% over the 2012 consumption for the low and high scenarios as shown in fig.4.6

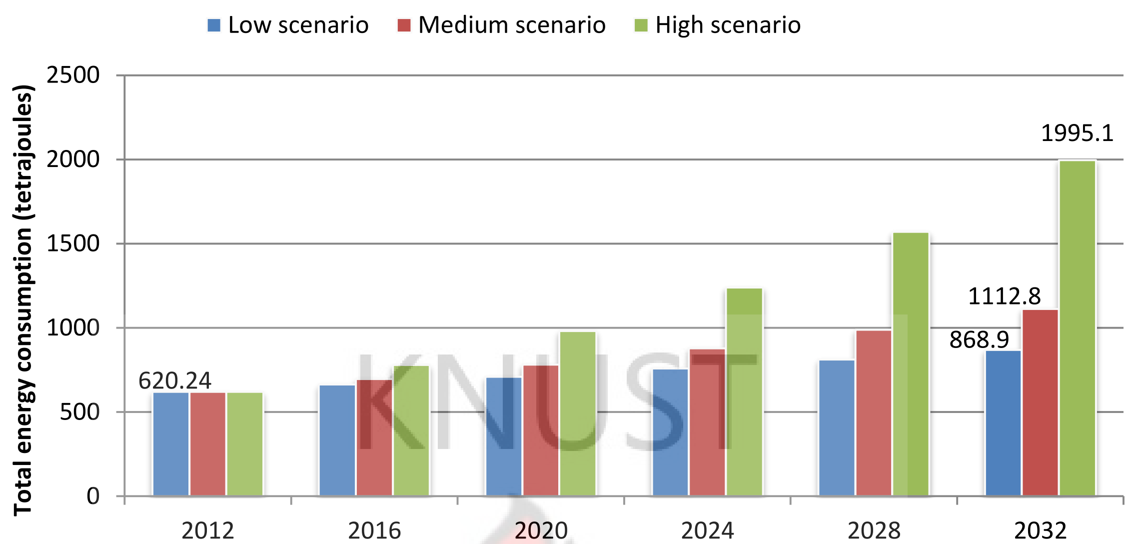

Fig.4.6: Projection of total energy (gasoline and woodfuel) consumption from 2013 to 2032

4.4 Comparison of ethanol potential with fuel demand

The ethanol production potential is compared to fuel demand in the district using the energy content of the fuels for the present situation and also for 2032. Details of the values are presented in Table 4.7. The estimation indicates that using ethanol energy potential from average biomass production between 2003 to 2012, annual fuel demand of 620.2 TJ outweighs ethanol potential for both the low and medium scenario potentials of 199.2TJ and 498.1 TJ respectively. Only in the high scenario is ethanol potential of 796.9TJ more than the estimated fuel consumption in 2012. In 2032, ethanol potential from all three growth scenarios would more than substitute gasoline and woodfuel demand.

Table 4.7: Comparison of Bioethanol energy production potential with Fuel energy demand in the Lawra-Nandom District

Year		Low scenario	Medium scenario	High scenario
	Ethanol production potential	199.2 TJ	498.1 TJ	796.9 TJ
2003-2012 average	Total gasoline and cooking fuel demand	620.2 TJ	620.2 TJ	620.2 TJ
	Surplus ethanol	**-403 TJ**	**-122.1 TJ**	**176.7 TJ**
	Ethanol production potential	1,190.4 TJ	2,976.1 TJ	4,761.7 TJ
2032	Total gasoline and cooking fuel demand	868.9 TJ	1,112.8 TJ	1,995.1 TJ
	Surplus ethanol	**321.5 TJ**	**1,863.3 TJ**	**2766.6 TJ**

4.5 Evaluation of net energy balance of ethanol production from crop residues

In the net energy balance analysis, all units of fuels were converted to energy units. The total ethanol energy potential ranges from 199.22 TJ in the low scenario to 796.87 TJ in the high scenario. Energy balance analysis was performed for an average ethanol potential, using the average between the low and high scenarios. Based on the ethanol energy potential in 2012, gross energy output, E_{gross} = 498.045 TJ with average crop residues at 67,951.5 tonnes which translates to E_{gross} /tonne of 7330 MJ/tonne. The average time taken to harvest an average residue of 55.78 kg was 8.5 minutes and that for gathering an average residue of 55.78 kg was 9.44 minutes. The details are presented in appendix F.

Based on the time taken to harvest/collect the average residues of each crop and by simple proportion, the time taken to harvest and collect one ton of residues was 1.82 hours and 2.82 hours respectively. The details are presented in appendix F.

Using equation 3.9 and 3.10 as shown previously in the methodology section (Chapter 3), the energy required to prepare residues for ethanol production as well as other activities in the chain including harvesting, collection/gathering and transportation to processing site are summarised in Table 4.8. Harvesting of residues is assumed to be done manually due to the scale of farm operations. Farms in the district are small-scale and often scattered across the entire land space. Based on the calculation for the various scenarios (low, medium and high), the quantity of residues that would be available for biofuel production after meeting other applications (animal feeding and other uses) ranges from 27,180.6 tonnes to 108,722.4 tonnes per annum. The plant processing capacity is therefore assumed to be 130,000 tonnes/year

Table 4.8: Energy expended to prepare residues of different crops

Crop type	Energy required to harvest residue (MJ/tonne)	Energy required to gather residue (MJ/tonne)	Energy required to transport residue (MJ/tonne)
Millet	8.33	5.50	61.39
Sorghum	6.36	5.50	61.39
Maize	13.75	5.50	61.39
Groundnut	0	5.50	61.39
Average	**9.48**	**5.5**	**61.39**

The energy required for harvesting groundnut is allocated to the main product because the whole groundnut has to be uprooted before the product can be plugged from the straw hence the energy require to harvest the residue is zero. Only energy to collect is required.

The total average energy input for processing lignocellulosic biomass through biochemical conversion is between 5229 MJ/tonne and 6929 MJ/tonne (Zhu and Zhuang, 2012). Thus, the net energy analysis of ethanol production is indicated in Table 4.9.

The net energy balance is positive and the ratio of biofuel output to the energy input is greater than one which is an indication that the biofuel production would be beneficial.

Table 4.9: Net energy analysis of ethanol production from lignocellulosic biomass through biochemical route

Activity	Energy input (MJ/tonne biomass)
Harvesting of crop residues	9.50
Collection of crop residues	5.50
Transportation of crop residues	61.39
Biorefinery operation	3150*
High solids enzymatic saccharification and fermentation	500*
Distillation and separation	1600*
Other biorefinery operation	250*
Total energy input	**5576.4**
Total Biofuel Energy Output	**7,330**
Net energy balance	**1,753.6**
Ratio of biofuel output to energy input	**1.31**

*Values taken from Zhu and Zhuang (2012)

4.6 Financial assessment

Based on field experiments conducted for an 8-hour working day, the average farm labourer is able to harvest approximately 3.14 tonnes/day of biomass at a cost of GH¢ 3.18 per tonne. The costs of other processes are listed in Table 4.10. Currently, there are no operating lignocellulosic biofuel plants in the country, therefore the data on other operating costs (processing costs, repairs and maintenance costs, utility costs and administrative costs) and investment costs were taken from the literature for the financial viability analysis. The unit cost of feedstock studied is listed in Table 4.11

Table 4.10: Summary of feedstock cost in the studied district

Item	GH¢/t	GH¢/L
Harvesting cost	3.18	0.009
Collection cost	4.81	0.014
Transportation cost	5.97	0.017
Total feedstock cost	**13.96**	**0.041**

NB: 1 tonne of residues give 342L of bioethanol

Table 4.11: Cost data on biofuel production

Item	$/gal	$/L*	GH¢/L (Using December, 2013 exchange rate of GH¢2.162 to $)
Investment/capital cost*	6.76	1.49	3.22
Operating costs**			
Processing costs:	0.76		
d) Direct labour cost		0.013	0.028
e) Chemicals/enzymes		0.2	0.432
f) Denaturants		0.02	0.043
g) Water		0.001	0.002
Repairs and maintenance costs		0.036	0.078
Administrative costs		0.012	0.026
Property taxes and insurance		0.021	0.045
Total operating costs excluding feedstock costs		**0.303**	**0.655**

Source: *MaAloon (2008) and **APEC (2010)

The following factors were assumed in the financial analysis.

1. A hypothetical plant with 130,000 tonnes annual production capacity (i.e. about 40 million litres; assuming a theoretical yield of 342 L/ton)

2. Selling price of ethanol to be GH¢1.53/L (approximately 70% of gasoline price in the country as at December, 2013)

3. The feedstock cost is assumed to increase by 2% annually and the operating cost by 3%

4. The corporate tax is 25%

5. Discount rate is taken as 19% (government borrowing rate as at December 2013)

6. The plant is expected to produce 20 million litres in the first year, 30 million in second year, 35 million in the third year and reach the maximum of 40 million litres from the fourth year onward.

7. A 30 year lifespan for the processing plant

From the data above, the NPV was calculated to be GHC 2 million with an IRR of 19.3%. The

NPV is positive which indicates that the project is profitable. The IRR is just about equal to the discount rate of 19%. The closeness of the IRR to the discount rate indicates that a slight upward change in project costs could have negative impacts on the financial feasibility of the project. A sensitivity analysis was therefore performed to determine the impact of a simultaneous 5% increase in costs and a 5% decrease in revenue. This change would not make the project profitable because NPV becomes negative (GHC- 6.7 million) with an IRR less than the discount rate. Sensitivity was run for a project that is granted a tax rebate for 10 years. For this case, the NPV increases to GHC 30 million with a more impressive IRR of 23.5%.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study provided a comprehensive assessment of agricultural crop waste biomass potential for second generation bioethanol production in the Lawra-Nandom district.

The RPR of four major crops such as maize, sorghum, millet and groundnut were determined in the field. The study found the RPR of maize, sorghum, millet stalks and groundnut vine determined from the field as 1.15, 4.75, 5.53 and 1.73 respectively. The study found that the total annual crop residues production in the Lawra district is about 271, 807 tonnes. Sorghum crop generates the largest quantity of residues of about 160, 410 tonnes annually with 59.02% share of the total crop residues. The study revealed that, out of the 271,807 tonnes of crop residues generated annually, the actual amount of residues that would be available for biofuel production were 27,181 tonnes (low scenario), 67,952 tonnes (medium scenario) and 108,723 tonnes (high scenario). Using growth rates of crop production from 2003-2012, it is projected that residue will increase by close to 500% of the 2012 production by 2032.

The research has found that the current biofuel that could be produced under the low, medium and high scenarios were 9.397 million litres, 23.493 million litres and 37.588 million litres respectively.

The study found that the current annual petrol consumption in the studied district is about 1.066 million litres (using the year 2012 as the baseline). In 2032, the petrol consumption will increase between 40.2% and 650.1% under the low and high scenarios.

The survey also revealed that the average charcoal consumed by a household per day is 1.14kg and the average firewood consumed by a household is 3.17kg per day. It was also found that in 2032, woodfuel consumption would increase between 40.2% and 150.1% for the low and high scenarios.

The study found that the total energy consumption (both petrol and woodfuel) in the studied district was 620.24TJ. The projection of future energy consumption revealed that in 2032, the energy consumption in the district would increase between 40.2% and 221.1% for the low and high scenarios.

The study also suggests that the residues in the district will be able to produce more than enough bioethanol energy by 2032 to meet the entire fuel energy (petrol and woodfuel) demand in the district.

The study found that the gross energy produced per tonne from the agricultural residues was 7330MJ/t. It was also found that the energy required for harvesting, collecting and transporting the residues were 9.5MJ/t, 5.5MJ/t and 61.39MJ/t respectively. Furthermore, the research revealed that the total energy input (from harvesting through to conversion of the residue to bioethanol) was 5,611.94MJ/t and the bioethanol output was 7,330MJ/t. The net energy balance was found to be 1,718.66MJ/t and the ratio of bioenergy output to the total energy input was 1.31. The research found that the bioethanol production in the district would be beneficial since the net energy balance was positive and the ratio of bioethanol output to the energy input was greater than one.

The study found that the total feedstock cost was GH¢13.96/t. It was also established that the net present values of the cash flows of the hypothetical plant was positive (An NPV of GHC 2 million and an IRR of 19.3%) which means the biofuel plant is financially viable. The sensitivity analysis carried out indicates that a fall in revenue by 5% and an increase in operating cost by 5% results in a negative NPV. However, a 10 year environmental tax rebate by government would increase NPV to GHC 30 million.

It is expected that government will implement policies in the country's Renewable Energy Law that will encourage the utilization of waste biomass for energy production.

5.2 Recommendations

There are a number of issues that need to be addressed if second generation biofuel is to be established; hence the researcher suggests the following for further work:

- The RPR determined in this research only related to one crop season. Since there are seasonal variations in crop yield, there is the need to further determine the RPR of the various crops for some number of seasons and the average RPR calculated. Also, RPR of the major crops in other districts of the country should be determined and the national average be calculated.

- There is the need for establishment of a pilot biofuel plant in the district so as to determine the actual biofuel yield of the various crop residues and to compare with the theoretical yield. In addition, the pilot plant would help to establish the actual conversion cost of second generation biofuel production and the actual energy required to convert the feedstock to biofuel.
- There is the need to assess greenhouse gases (GHGs) impacts of second generation biofuel production relating to the feedstock production and conversion in the district.
- Research into the issues of social acceptability and market potential of biofuels in the country is recommended

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APPENDICES

APPENDIX A: Production of major crops in the Lawra-Nandom district from 2003 to 2012

YEAR	CROP PRODUCTION IN METRIC TONNES (Mt)				
	MAIZE	SORGHUM	MILLET	GROUND NUTS	TOTAL
2003	1,220	8,020	5,270	4,670	**19,180**
2004	1,573	8,749	4,239	6,793	**21,354**
2005	1,865	42,569	6,515	12,948	**63,897**
2006	1,953	42,932	5,794	16,951	**67,630**
2007	1,340	26,164	5,319	16,428	**49,251**
2008	1,968	46,999	7,448	17,424	**73,839**
2009	3,240	59,730	20,320	20,700	**103,990**
2010	4,680	47,784	17,920	24,288	**94,672**
2011	3,766	34,756	14,629	22,106	**75,257**
2012	6,411	10,334	40,327	9,448	**66,520**
AVERAGE CROP PRODUCTION	**2,801.6**	**32,803.7**	**12,778.1**	**15,175.6**	**63,559**

Source: Statistics, Research and Info. Directorate (SRID), MOFA (2013)

APPENDIX B: DETERMINATION OF RPR AND MOISTURE CONTENT OF CROP RESIDUES IN LAWRA-NANDOM DISTRICT

Table B.1 : RPR OF MILLET RESIDUES IN LAWRA-NANDOM DISTRICT

CROP: MILLET						
FARM 1	**PLOT**	**PRODUCT (Kg)**	**RESIDUE (Kg)**		**RPR**	
			STALKS	**HUSK**	**STALKS**	**HUSK**
	1	12.32	81.15	4.08	6.58685	0.331169
	2	17.42	92.12	4.93	5.28817	0.283008
	3	15.98	86.31	4.73	5.40113	0.295995
AVERAGE			**86.526667**		**5.75872**	**0.303391**
FARM 2	1	16.6	142.7	4.91	8.59639	0.295783
	2	20.54	145.2	5.31	7.06913	0.25852
	3	14.87	103.2	4.42	6.94015	0.297243
AVERAGE			**130.36667**		**7.53522**	**0.283849**
FARM 3	1	14.28	57.1	4.22	3.9986	0.295518
	2	13.83	41.32	3.81	2.98771	0.275488
	3	18.35	53.31	4.51	2.90518	0.245777
AVERAGE			**50.576667**		**3.29716**	**0.272261**
AVERAGE FOR THE THREE MILLET FARMS					**5.53037**	**0.2865**

Table B.2: RPR of sorghum residues

CROP: SORGHUM						
FARM 1	**PLOT**	**PRODUCT**	**RESIDUE Kg**		**RPR**	
			STALKS	**HEADS**	**STALKS**	**HEADS**
	1	20.95	117.64	3.45	5.61527	0.164678
	2	18.76	85.21	2.56	4.54211	0.136461
	3	25.36	91.03	2.83	3.58951	0.111593
AVERAGE		**21.69**	**97.96**	**2.946667**	**4.5823**	**0.137577**
FARM 2	1	15.58	106.7	2.85	6.84852	0.182927
	2	19.28	72.86	1.92	3.77905	0.099585
	3	22.81	96.23	2.45	4.21876	0.107409
AVERAGE			91.93		**4.94878**	**0.129974**
	1	7.34	48.5	1.21	6.60763	0.16485
FARM 3	2	8.24	35.31	1.31	4.28519	0.158981
	3	15.62	51.14	2.22	3.27401	0.142125
AVERAGE			44.983333		**4.72228**	**0.155319**
AVERAGE FOR THE THREE SORGHUM FARMS					**4.75112**	**0.140957**

Table B.3: RPR of maize residues

CROP: MAIZE								
FARM 1	**PLOT**	**PRODUCT**	**RESIDUE**			**RPR**		
			STALKS	**HUSKS**	**COB**	**STALKS**	**HUSKS**	**COB**
	1	24.75	26	5.35	14.15	1.05050	0.21616	0.571717
	2	22.58	24.86	4.81	12.31	1.10097	0.21302	0.545173
	3	25.82	34.61	6.82	15.89	1.34043	0.26413	0.615414
AVERAGE			**28.49**			**1.16397**	**0.23110**	**0.577435**
FARM 2	1	35.54	38.6	7.94	20.02	1.0861	0.22341	0.563309
	2	28.12	32.42	6.31	13.4	1.15291	0.22439	0.476529
	3	24.65	29.82	4.5	11.72	1.20973	0.18255	0.475456
AVERAGE			**33.61333**			**1.14958**	**0.21012**	**0.505098**
FARM 3	1	27.82	31	6.38	16.87	1.11430	0.22933	0.606398
	2	23.83	26.72	6.95	15.72	1.12127	0.29164	0.659673
	3	30.21	34.91	7.72	18.31	1.15557	0.25554	0.606091
AVERAGE			**30.87666**			**1.13038**	**0.25884**	**0.624054**
AVERAGE FOR THE THREE MAIZE FARMS						**1.14798**	**0.23335**	**0.568862**

Table B.4: RPR of Groundnut residues

CROP:GROUNDNUTS						
FARM 1	**PLOT**	**PRODUCT**	**RESIDUE**		**RPR**	
			STRAW	**SHELL**	**STRAW**	**SHELL**
	1	19.21	18.25	5.49	0.95003	0.285789
	2	14.23	22.45	3.52	1.57765	0.247365
	3	20.12	35.43	7.1	1.76093	0.352883
AVERAGE		17.853333	25.376667	5.37	1.42954	0.295345
FARM 2	1	12.02	23.41	5.18	1.94759	0.430948
	2	15.21	29.24	7.32	1.92242	0.481262
	3	8.78	17.61	2.61	2.00569	0.297267
AVERAGE		12.003333	23.42	5.036667	1.95857	0.403159
FARM 3	1	13.5	25.2	3.24	1.86667	0.24
	2	12.1	22.41	4.8	1.85207	0.396694
	3	16.31	28.21	6.34	1.72961	0.388719
AVERAGE		13.97	25.273333	4.793333	1.81612	0.341804
average for the three groundnut farms					**1.73474**	**0.34677**

Table B.5: MOISTURE CONTENT OF MILLET RESIDUES

CROP: MILLET					
MILLET STALKS					
FARM	PLOT	MOISTURE CONTENT (WET BASIS)			
		Ww	Wd	Ww-Wd	MC = [(Ww-Wd)/Ww]*100%
1	1	221.15	80.16	140.99	63.75310875
	2	214.27	75.17	139.1	64.91809399
	3	244.65	94.74	149.91	61.27529123
AVERAGE					**63.31549799**
2	1	216.66	86.72	129.94	59.97415305
	2	286.96	108.9	178.06	62.05045999
	3	277.81	105.4	172.41	62.06040099
AVERAGE					**61.36167135**
3	1	162.9	60.63	102.27	62.78084715
	2	298.28	100.14	198.14	66.42751777
	3	165.51	51.42	114.09	68.93239079
AVERAGE					**66.04691857**
AVERAGE FOR THE THREE MILLET FARMS					**63.57469597**
MILLET HUSK					
FARM					
1		150.8	134.35	16.45	10.90848806
2		109.2	95.31	13.89	12.71978022
3		85.81	76.23	9.58	11.16419998
AVERAGE					**11.59748942**

Table B.6: MOISTURE CONTENT OF SORGHUM RESIDUES

CROP: SORGHUM					
SORGHUM STALKS					
FARM	PLOT	MOISTURE CONTENT (WET BASIS)			
		Ww	Wd	Ww-Wd	MC = [(Ww-Wd)/Ww]*100%
1	1	250.21	100.6	149.61	59.79377323
	2	185.46	77.68	107.78	58.1149574
	3	182.37	66.6	115.77	63.48083566
AVERAGE					60.46318877
2	1	317.99	106.06	211.93	66.6467499
	2	145.21	56.08	89.13	61.38007024
	3	158.69	61.9	96.79	60.99313126
AVERAGE					63.00665047
	1	92.8	33.96	58.84	63.40517241
3	2	68.1	27.37	40.73	59.80910426
	3	147.3	55.19	92.11	62.53224711
AVERAGE					61.91550793
AVERAGE FOR THE THREE SORGHUM FARMS					**61.79511572**
SORGHUM HEADS					
FARM					
1		80.31	78.99	1.32	1.64363093
2		94.21	91.51	2.7	2.865937799
3		75.41	72.61	2.8	3.713035406
AVERAGE FOR THE THREE FARM					**2.740868045**

Table B.7 determination of moisture content of maize residues

CROP: MAIZE					
MAIZE	**STALKS**				
FARM	PLOT	MOISTURE CONTENT (WET BASIS)			
		Ww	Wd	Ww-Wd	MC = [(Ww-Wd)/Ww]*100%
1	1	91.43	24.71	66.72	72.97385978
	2	116.94	29.7	87.24	74.60236018
	3	140.18	30.53	109.65	78.2208589
AVERAGE					**75.26569295**
2	1	95.57	22.91	72.66	76.02804227
	2	79.44	21.42	58.02	73.03625378
	3	187.13	46.68	140.45	75.05477476
AVERAGE					**74.70635693**
	1	177.6	48.53	129.07	72.67454955
3	2	157.35	45.56	111.79	71.0454401
	3	137.93	41.88	96.05	69.63677228
AVERAGE					**71.11892064**
AVERAGE FOR THE THREE SORGHUM FARMS	**THE THREE MAIZE FARMS**				**73.69699018**
MAIZE HUSKS					
FARM					
1		84.36	31.2	53.16	63.01564723
2		54.44	20.82	33.62	61.75606172
3		65.81	25.2	40.61	61.70794712
AVERAGE	**FOR THE THREE FARMS**				**62.15988536**
MAIZE COBS					
FARM					
1		170.26	144.73	25.53	14.99471397
2		142.06	123.56	18.5	13.02266648
3		181.23	153.12	28.11	15.51067704
AVERAGE	**FOR THE THREE FARMS**				**14.5093525**

Table B.8 : Determination of moisture content of groundnut residues

CROP: GROUNDNUTS					
FARM	PLOT	MOISTURE CONTENT (WET BASIS)			
		Ww	Wd	Ww-Wd	[(Ww-Wd)/Ww]*100
1	1	77.8	63.35	14.45	18.57326478
	2	45.92	39.64	6.28	13.67595819
	3	51.12	40.01	11.11	21.73317684
AVERAGE					17.99413327
2	1	68.24	52.1	16.14	23.65181712
	2	72.31	59.4	12.91	17.85368552
	3	41.56	35.61	5.95	14.31665063
AVERAGE					18.60738442
3	1	54.81	41.2	13.61	24.83123518
	2	63.21	52.4	10.81	17.10172441
	3	73.51	60.3	13.21	17.97034417
AVERAGE					19.96776792
AVERAGE FOR THE THREE GROUNDNUT FARMS					**18.85642854**

APPENDIX C: HOUSEHOLD FUEL CONSUMPTION SURVEY SHEET

Name of Household	Number of People	Visit # 1 Date &Time:		Visit # 2 Date & time:				Visit#3 Date & time:	
		New Charcoal Kg	New wood Kg	Unused Charcoal Kg	Unused Wood Kg	New Charcoal Kg	New wood Kg	Unused Charcoal Kg	Unused Wood Kg

APPENDIX D: **Using Regression Analysis to obtain the average growth rate of crop production in the district**

Table D: Lawra District Annual Growth rate of crop production

Year	X	Y	lnY	X^2	XlnY
2003	0	19,180	9.86	0	0
2004	1	21,354	9.97	1	9.97
2005	2	63,897	11.07	4	22.14
2006	3	67,630	11.12	9	33.36
2007	4	49,251	10.8	16	43.2
2008	5	73,839	11.21	25	56.05
2009	6	103,990	11.55	36	69.3
2010	7	94,672	11.46	49	80.22
2011	8	75,257	11.23	64	89.84
2012	9	66,520	11.11	81	99.99
SUM	**45**		**109.38**	**285**	**504.07**

$Y = mX + c$

$\ln Y = mx + c$

$\sum \ln Y = cN + m\sum X$

$\sum XY = c\sum X + m\sum X^2$

$c = (\sum \ln Y \sum X^2 - \sum X \sum X \ln Y)/[N\sum X^2 - (\sum X)^2]$

$m = (\ln\bar{Y} - c)/\bar{x}$

from the above, $c = \{(109.38 x 285) - (45 x 504.07)\}/[(10 x 285) - (45)^2] = 10.29$

$M = (10.94 - 10.29)/4.5 = 0.1444$, NB: $\ln\bar{Y} = 109.38/10 = 10.94$, $\bar{x} = 45/10 = 4.5$

$r = e^m - 1 = e^{0.144} - 1 = 0.155 = 15.5\%$

Table D.2: Regional Growth rate of crop production (Upper West)

Year	X	Y	lnY	X^2	XlnY
2003	0	373,150	12.83	0	0
2004	1	317,276	12.67	1	12.67
2005	2	322,820	12.68	4	25.36
2006	3	352,650	12.77	9	38.31
2007	4	274,050	12.52	16	50.08
2008	5	386,000	12.86	25	64.3
2009	6	454,828	13.03	36	78.18
2010	7	480,981	13.08	49	91.56
2011	8	380,079	12.85	64	102.8
2012	9	409,092	12.92	81	116.28
SUM	**45**		**128.21**	**285**	**579.54**

from the above, c ={ 128.21x285)-(45x579.54)}/[(10x285)-(45)^2 = 12.68

M = (12.82-12.68)/4.5 = 0.0311, NB: $\ln\bar{Y}$ = 128.21/10 =12.821, $\bar{x}$ = 45/10 = 4.5

r= e^m -1 = $e^{0.0311}$ -1 = 0.0316 = 3.16%

Average growth rate = (15.5%+3.16%)/2 = 9.33%

APPENDIX E: **Using Regression Analysis to obtain the average growth rate of woodfuel production in the district**

Table E.1: Determination of growth rate of charcoal consumption using National charcoal consumption data

Year	X	Y	lnY	X^2	XlnY
2003	0	1,006.90	6.91	0	0
2004	1	1,042.20	6.95	1	6.95
2005	2	1,043.70	6.95	4	13.9
2006	3	1,051.70	6.96	9	20.88
2007	4	1,066.20	6.97	16	27.88
2008	5	1,070.80	6.98	25	34.9
2009	6	1,071.50	6.98	36	41.88
2010	7	1,072.70	6.98	49	48.86
2011	8	1,233.60	7.12	64	56.96
2012	9	1,416.60	7.26	81	65.34
	45		70.06	285	317.55

C= (70.06*285-45*317.55)/(10*285-45^2) = 6.882

M = (7.006-6.882)/4.5 = 0.02756

r= e^m -1 = $e^{0.02756}$ -1= 0.0279 =2.79%

APPENDIX F: Time taken to harvest/gather agricultural residues

Table F.1 : Time taken to harvest/gather 100m^2 plot of residues

Crop	Average Residues (Kg)	Time taken to harvest Residues (minutes)	Time taken to gather Residues (minutes)
Millet	89.16	11.37	15.09
Sorghum	78.29	7.62	13.25
Maize	30.99	6.52	5.24
Groundnut	24.69	0	4.18

Table F.2 : Time taken to harvest/gather one ton of residues

Crop	Time taken to harvest one ton of Residues (Hours)	Time taken to gather one ton of Residues (hours)
Millet	2.13	2.82
Sorghum	1.62	2.82
Maize	3.51	2.82
Groundnut	0	2.82

APPENDIX G: Financial analysis of Hypothetical biofuel plant

Table G: Financial analysis of Hypothetical biofuel plant with annual capacity of 130,000 tons (about 40 million litres)

Revenue Parameter	Year										
	0	1	2	3	4	5	6	7	8	9	10
Production (million Litres)	0.00	20.00	30.00	35.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
EOH selling price (GH¢/L)	0.00	1.53	1.57	1.61	1.65	1.69	1.73	1.77	1.82	1.86	1.91
Revenue (GH¢ million)	**0.00**	**30.6**	**47.05**	**56.26**	**65.91**	**67.55**	**69.24**	**70.97**	**72.75**	**74.57**	**76.43**
Cost Parameter											
Capital cost (GH¢ million)	- 130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feedstock cost (GH¢ million)	0.00	0.82	1.25	1.49	1.74	1.77	1.80	1.84	1.87	1.90	1.94
Operating cost (GH¢ million)	0.00	13.10	20.24	24.30	28.56	29.34	30.13	30.92	31.70	32.49	33.27
Total cost (GH¢ million)	**- 130.00**	**13.92**	**21.49**	**25.79**	**30.30**	**31.12**	**31.93**	**32.75**	**33.57**	**34.39**	**35.21**
PBT (GH¢ million)	- 130.00	16.68	25.55	30.47	35.61	36.44	37.31	38.22	39.18	40.18	41.22
Tax (GH¢ million) = 25%	0.00	4.17	6.39	7.62	8.90	9.11	9.33	9.56	9.79	10.04	10.31
PAT/Net cash flow (GH¢ million)	- 130.00	12.51	19.17	22.85	26.71	27.33	27.98	28.67	29.38	30.13	30.92

	11	12	13	14	15	16	17	18	19	20
	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
	1.96	2.01	2.06	2.11	2.16	2.22	2.27	2.33	2.39	2.45
	78.34	**80.30**	**82.31**	**84.36**	**86.47**	**88.64**	**90.85**	**93.12**	**95.45**	**97.84**
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.97	2.00	2.03	2.07	2.10	2.13	2.16	2.20	2.23	2.26
	34.06	34.85	35.63	36.42	37.20	37.99	38.78	39.56	40.35	41.13
	36.03	**36.85**	**37.67**	**38.48**	**39.30**	**40.12**	**40.94**	**41.76**	**42.58**	**43.40**
	42.31	43.45	44.64	45.88	47.17	48.51	49.91	51.36	52.87	54.44
	10.58	10.86	11.16	11.47	11.79	12.13	12.48	12.84	13.22	13.61
31.73		32.59	33.48	34.41	35.38	36.39	37.43	38.52	39.65	40.83

21	22	23	24	25	26	27	28	29	30
40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
2.51	2.57	2.63	2.70	2.77	2.84	2.91	2.98	3.05	3.13
100.28	**102.79**	**105.36**	**107.99**	**110.69**	**113.46**	**116.30**	**119.21**	**122.19**	**125.24**
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.30	2.33	2.36	2.39	2.43	2.46	2.49	2.53	2.56	2.59
41.92	42.71	43.49	44.28	45.06	45.85	46.64	47.42	48.21	48.99
44.22	**45.03**	**45.85**	**46.67**	**47.49**	**48.31**	**49.13**	**49.95**	**50.77**	**51.59**
56.07	57.76	59.51	61.32	63.20	65.15	67.17	69.26	71.42	73.65
14.02	14.44	14.88	15.33	15.80	16.29	16.79	17.31	17.85	18.41
42.05	43.32	44.63	45.99	47.40	48.86	50.38	51.94	53.56	55.24

NPV = GH¢2.37 million and IRR = 19.3%

When the revenue falls by 5% and the total operating cost increases by 5%, the NPV = GH¢-16.00 million