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**TITLE: Assessment of Biofuel Potential on Marginal Lands and from Waste Vegetable Oil Resources in a Ghana**

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ASSESSMENT OF BIOFUEL POTENTIAL ON MARGINAL LANDS AND FROM WASTE VEGETABLE OIL RESOURCES IN A GHANA

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**Dedication**

I dedicate this thesis to my family, friends and all interested in clean and sustainable energy.

**Statement of Author**

By my signature below, I declare that this thesis is my work. I have followed all ethical principles of the scholarship in the preparation, data collection, data analysis, and completion of this thesis. I have given all scholarly matter recognition through accurate citations and references. I affirm that I have cited and referenced all sources used in this document. I have made every effort to avoid plagiarism.

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**Biographical Sketch**


Angela Okuley was born on 29/04/1994 in Accra, Ghana. She was enrolled in preschool in 1997 at Osu, Accra. She had her basic education in the same city between 1999 to 2008 where she was the Head Girl in Primary 6 and the health prefect in her final year in the Junior High School (JHS). In 2008, she sat for the BECE at Osu Presbyterian Girls' JHS where she completed with the best grade that year. She furthered to Krobo Girls' Presbyterian Senior High School between 2008-2012 to read General Science with her elective courses as; Elective Chemistry, Elective Physics, Elective Biology and Further Mathematics. While in Krobo Girls', she was a sports girl and won a bronze medal as a long distance athlete, she was also awarded the best girl of her house (Neuk). In September 2012, she continued to University of Energy and Natural Resources in Sunyani, Ghana where she read BSc Renewable Energy Engineering when the program was first introduced in the country as an undergraduate course due to the energy challenges the country faced as at then to produce more human resource in the sector, the interest in energy was birthed there. She was maintained as a teaching assistant in her university when she completed in 2016 till 2017 when she gained admission to the Pan African University Institute of Water and Energy Sciences to Pursue an MSc in Energy Engineering. During her undergraduate program, she, with a team of other energy engineering students designed a multi-functional extension board, this was to help them charge and use some electrical appliances when there is no light, due to the persistent load shedding in the country then. She has worked on other projects which include: Assessment of waste water treatment at a regional hospital in Ghana, Design of a biogas digester for electrification: a case study of Sunyani Senior High School, and for her master thesis, she worked on Assessment of potential of biofuel in Ghana from marginal lands and waste vegetable oils. She is in charge of Energy Management, in the Jua House, a green house built by the Jua Jami team of PAUWES in the Solar Decathlon Africa Competition. She is has interned with the Mechanical & Electrical engineering Department of TV3 Limited a leading Media company in Ghana, The Electrical and Electronics department of Cocoa Processing Company Ltd. Ghana premiere Cocoa Processing Company and the Renewable Energy and Energy Efficiency & Climate Change Department of the Energy Commission, Ghana, the main regulators of the market players in the energy sector. She has volunteered with several groups & NGOs including NSESA foundation which organizes bootcamps for Processing and Arduino Coding lessons and innovations for high school and university students. She aims at being a part of the solution to the energy issues in her country and the world at last. She has good IT skills. She has basic skills in Arduino, C++, She can use softwares like Dreamwaver, Photoshop, Adobe Premier Pro, AVS Video Editor, RetScreen, HOMER, etc. She has interest in research in energy and looks for forward to becoming a practicing engineer, a researcher and a lecturer.

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**List of Abbreviations**

AHP- Analytic Hierarchy Process

ASTM - American Society for Testing and Materials

$CH_4$ - Methane

$CO_2$ - Carbon dioxide

EPA - Environmental Protection Agency

FFA - Free Fatty Acids

GDP - Gross Domestic Pro

GWP - Global Warming Potential

GHG - Green House Gas

HFC - Hydroflourocarbons

KTOE - kilotone of oil equivalent

LULC - Land Cover Land Use

MoFA- Ministry of Food Agency

Mt – Mega tonne

MW- Mega Watt

NER- Net Energy Ratio

NGA - National Greenhouse Accounts

$N_2O$ - Nitrogen dioxide

NPA-National Petroleum Authority

OEC- Observatory of Economic Complexity

PFC - Perflourocarbons

PSI- Presidential Special Initiative

REs- Renewable Energies

SDG- Sustainable Development Goals

$SF_6$ - Sulfur hexafluoride

SNEP- Strategic National Energy Plan

TOPSIS- Technique for Order of Preference by Similarity to an Ideal Situation

$tCO_2e$ – tons of carbon dioxide equivalent

VRA-Volta River Authority

WVO- Waste Vegetable Oil

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**Abstract**

Climate change and its numerous effects has called for the need to consider green and cleansourced energy alternatives. Biofuel promises to be a great option. This research aims at Assessing the Biofuel Potential on Marginal Lands and from Waste Vegetable Oil Resources in Ghana. According to literature, Ghana seeks to integrate 20% biofuels into the transport mix by 2030 to reduce emission among other pros. Biodiesel from Jatropha , Soya bean oil, oil palm, coconut oil, etc. has been tested to that effect. The challenge however has been the food versus energy a debate. Questionnaires were used to determine Waste Vegetable Oil resources from households, wayside vendors and hotels. AHP and TOPSIS were used to select energy crops based on ecological requirements. A suitability analysis was then done using ArcGIS. It was also revealed that, 395.9litres of WVO can be generated monthly as biodiesel feedstock from 101 households, 32 wayside vendors and 200 hotels. This will reduce our GHG emissions by 1.0634 $tCO_2e$. Considering the potential of biofuel in Ghana. It will be expedient to consider introducing biodiesel into our energy sector especially as transport fuel in our quest to minimize GHG emissions and to augment the heavy reliance on fossil fuels.

**Keywords:** Biodiesel, Waste Vegetable Oil, Green House Gases, marginal land, Jatropha

**Résumé**

Le changement climatique et ses nombreux effets ont nécessité la prise en compte d’autres sources d’énergie écologiques et propres. Le biocarburant promet d’être une excellente option. Cette recherche vise à évaluer le potentiel de biocarburant sur les terres marginales et à partir de ressources en huiles végétales usées au Ghana. Selon la littérature, le Ghana cherche à intégrer 20% de biocarburants dans le mix de transport d’ici 2030 afin de réduire les émissions, entre autres avantages. Le biodiesel issu du jatropha, l'huile de soja, l'huile de palme, l'huile de coco, etc. ont été testés à cet effet. Le défi a cependant été le débat sur le rapport nourriture-énergie. Des questionnaires ont été utilisés pour déterminer les ressources en huiles végétales résiduelles provenant des ménages, des vendeurs en bordure de route et des hôtels. AHP et TOPSIS ont été utilisés pour sélectionner des cultures énergétiques en fonction des exigences écologiques. Une analyse de pertinence a ensuite été effectuée à l'aide d'ArcGIS. Il a également été révélé que 395,9 litres de WVO peuvent être générés mensuellement comme matière première de biodiesel à partir de 101 ménages, 32 vendeurs en bordure de route et 200 hôtels. Cela réduira nos émissions de GES de 1,0634 tCO2e. Considérant le potentiel des biocarburants au Ghana. Il sera opportun d’envisager d’introduire du biodiesel dans notre secteur énergétique, en particulier comme carburant pour les transports, dans le but de réduire les émissions de gaz à effet de serre et d’accroître la dépendance à l’égard des combustibles fossiles.

**Mots-clés:** Biodiesel, Déchets d'huile végétale, Gaz de serre, terres marginales, Jatropha

# CHAPTER 1

# 1. INTRODUCTION

## 1.1 Background

Climate change and its numerous effects has called for several works to be done especially in the energy sector which happens to be one of the major contributors to climate change. The transportation sector globally is dominated by fossil fuel which contributes largely to climate change. Ghana like other African countries contributes marginally to the global volume of GHG emissions. A report revealed that, the country's total emissions for 2006 are estimated at 18.370 Mt (excluding those from the land-use, land-use change and forestry sectors), this is only about 0.06 % of the global carbon emissions which is about 29,190 Mt [1]. Despite this the country still seeks to reduce drastically to a very lower percentage if not completely reduce to zero the emissions since the climate change affects not just the polluter but the entire world.

The African continent though a relatively less contributor to GHG emission and climate change for that matter, are however the most vulnerability to the consequences since they are minimum adaptation measures due to lack of finances and structures. The black continent, specifically the sub-Saharan Africa has most of its countries having Agriculture has one of its main contributors to their economy, Ghana is no different.

Ghana has one of the fastest growing economies in the African continent and has made noticeable progress in reducing poverty. Research has it that, there has been reduced rainfall and drought in the country as a result of climate change, this possess a threat to the energy security and the seemingly fast growing economy of the country.

Hydropower ; from Akosombo, Kpong and Bui dams as at the time of the publication of this report in 2017 contributes about 54% to national generation capacity. VRA, the state-owned generation company, attempts to balance water levels in the Volta Lake due to increased evaporation and unreliable rainfall in the catchment area. Managing these risks along with reduced supplies of natural gas for the thermal plants which contributes the second highest percentage in the energy mix after hydropower results in undependable power generation. These results in frequent outages, the most intense of which occurred in early 2015 when power was off-and-on (known dumsor in the twi language) for up to 36 hours at a time, with real economic consequences. This caused the GDP growth to fall from 8.8 % in 2012 to 3.9 % in 2015, in part due to insufficient power from the grid. Which had led to jobs closing, reduction in production, etc. A recent study on projected water losses in the Volta Basin has revealed that, there will only be enough water for the hydropower dams to operate at 50 % of current capacity by 2050 [2]. This is alarming and calls for climate change adaption and mitigation to minimize its effect on the country.

In the USAID Climate change factsheet for Ghana, it was stated that, though the country has in recent times transited to an industry and service-oriented economy, about 45% of the workforce still depends on rain-fed agriculture. This threatens the food security and the economy of the country as agriculture accounts for about 42% of the GDP of the country. Though very essential to the economy, agricultural production in Ghana relies on small, rain-fed plots that are highly susceptible to the effects of climate change. Unpredictable precipitation patterns have adverse effects on agriculture production, as only 2 % of the irrigation potential of the country has been exploited. The increase in temperatures are predicted to lower yields in major staple crops (cassava, yams, plantains, maize and rice). It is projected that; for example, by 2050 maize yields will reduce by 7 % by 2050 and cassava yields will fall by 29.6 % by 2080. A complete crop failure is anticipated to occur approximately once every five years in Ghana’s northern region due to delayed or reduced rains. Cocoa, a major cash crop and Ghana’s second leading foreign exchange earner, is sensitive to high temperatures and drought. The suitable areas for cocoa production, which basically is along the coast are shrinking in size as temperature rises, floods increase, soil salinization and coastal erosion continues.

The fisheries sector which also contributes about 4.5% to the GDP, a relevant source of income and nutrition and provides livelihoods for about 2.2 million Ghanaians is threatened by climate change. The most-poverty severe region, which happens to be the Northern Savannah Ecological Zone a very delicate zone as agricultural production is centered there due to more reliable rains and an extended growing season there is likely to be faced by increased climate change effects. In the USAID factsheet, it was stated that, since the 1960s the average annual temperature increase over the years is about a degree Celsius which is an average increase of 0. 21°C decanally. The number of hot nights has also increased over the years, also rainfall levels was reported to have been highly variable according to the research ad a cumulative reduction of 2.4 per decade. There see levels has risen about 63mm in the past 30 years it has been forecasted that there will be an annual temperature increase between 1.4-5.8°C increase by 2080 with the maximum increases in the northern part of the country by 2040the overall rainfall will decrease by 4.4% and there will be erratic rainfall and intense rainfall during the wet season and lower precipitation levels during the dry season; larger decreases in the south [2].

Some of these we are already experiencing to some extent. These makes Climate change a great issue of concern and hence the need for climate change mitigation.

Currently Ghana has the highest number of climate change adaptation projects in West African region, focused on agriculture, human health, urban sustainability, ecosystem conservation freshwater resources, and institutional capacity building for addressing climate change [2].

Some of these projects include Climate Change Adaptation of AgroEcosystems in Ghana and Promoting Value Chain Approach to Adaptation in Agriculture both implemented by the Ministry of Food and Agriculture and Re-thinking Water Storage for Climate Change implemented by the International Water Management Institute (IWMI). But nothing in that regard had been recorded in this report as a contribution to Ghana's climate change adaptation in the energy sector.

As national and international targets has been set to mitigate climate change, the use of biofuels in the transport sector is a promising alternative. Ghana, like many other countries is considering pursuing this cause [3].

Hiking oil prices, concerns about climate change, and future energy supplies have contributed to growing interest in the use of liquid biofuels in the transport sector which, in turn, has driven largescale land acquisitions in developing countries for biofuel feedstock production, mainly jatropha [4].

This among other factors triggered the making of a national Bioenergy policy. One of the main challenge however, which is because of the increasing trend using land for growing energy crops has been the food, fuel versus land competition [3]. To forestall the food versus fuel debate, using “marginal lands” for bioenergy crop production, like jatropha has become the breakthrough but as to if the marginal lands are available and suitable for commercial production of jatropha Africa is not well examined especially in Africa [4]. Growing energy crops grown on marginal lands will provide cellulosic biomass without competition with food crops, and as well help to reclaim those lands and in addition a significant mitigation of greenhouse gases (GHG) without threating our food security [5].

As in the country’s Bioenergy Policy, Ghana aims at boosting security of oil supply, create employment, reduce import of oil as well reduce GHG emissions from the transportation sector by ensuring 20% of energy use in the transport sector by 2030 is from biofuels [3]. Biofuel can be biomass, biodiesel or biogas. This research seeks to acquire some information on biodiesel.

Biodiesel refers to diesel primarily from vegetable oil or animal fats. Biodiesel has two strong words; bio and diesel, the bio defines its renewable nature whereas the diesel reflects its use on diesel engines [6]. Diesel engines of trucks, cars, etc., can all run on biodiesel even that which is produced from waste cooking oil which is widely available. Considering the amount of waste oil daily produced and discarded, it is possible to produce enough biodiesel from WVO to fuel at least 10 vehicles [7]. Biofuels from feed stocks of plant-origin are considered as clean and renewable energy, which can be used as a biodiesel/ gasoline blend [8]. This will help us meet energy demands in a clean way. Biodiesel is one of the propitious options of fuel sources with many economic and environmental prospects such as its possible contribution to minimizing greenhouse gases emission. The characteristics of biodiesel and diesel have many similarities making biodiesel a reasonable fuel as an alternative to diesel [9]. It as well sustains engine life and minimizes the necessity for frequent maintenance. According to research, the qualities of lubrication of biodiesel is better than diesel from fossil. It is also safer to handle because it has less toxicity and more biodegradable. It has higher flash point. Also, it minimizes some exhaust emissions [10]. However, it is possible to install an extra fuel filter system if you have concerns about your engine lifespan [7].

The sub-Saharan region of the African continent is always said to be with a great potential for biomass production [11]. Kumah T. in his article, mentioned that, according to the United Nations Food and Agriculture Organization, sub-Saharan region of the African continent has more than 1 billion hectares of land with potential for rain-fed crop production [12]. According to an article in the Advanced biofuel USA journal, a hectare of jatropha plantation in the third year, is said to produce about 2.5-3.5 tonnes of seeds, from the $6^{th}$ year going however, this yield increases sharply to 5000-12,000 tonnes per hectare [12].

According to Kumah T., the jatropha seeds when rain fed and irrigated, have an oil yield of about 1-4 tonnes per hectare and 2.5-12 tonnes per hectare respectively.

Considering its worth, an analysis was conducted comparing jatropha oil and kerosene in Ghana in 2010. The estimated costs of jatropha oil and kerosene were US$0.085/liter and US$1.23/liter respectively, also the cost of biodiesel produced jatropha oil and petroleum diesel were estimated at US$0.99/liter and US$1.21/liter respectively [12].

According to Rossi et al, jatropha is gaining increasing relevance in Calabria as a biodiesel feedstock due to the fact that it acts as an alternative crop which can be grown on degraded and poor soils where foods cannot grow hence tackling the argument of food versus energy. Also, jatropha has relatively high oil content and lower $CO_2$ foot print compared to other biodiesel feedstock such as soybean and rape seed [13]. Also, according to Das and Jha, producing biodiesel from waste vegetable oil is somewhat simple and has several advantages [9]

Waste vegetable oil is considered as a renewable energy source because it doesn't include any additional carbon dioxide emissions to the environment like fossil fuels [9]. Waste Vegetable oil is derived from fried foods, especially from frying foods that require deep frying hence much oil needed to fry since the food must be immersed in the oil at high temperatures [14]. It is oil used in the preparation of food and can no longer be useful for its original purpose [10]. When frying, using any oil type, the oil is heated to about 170°C – 220°C. When the oil is heated to these temperatures in the presence of air, it undergoes thermal, physical and chemical degradation by reaction. The chemical degradation includes hydrolysis, oxidation and polymerization. This means, the oil quality changes and thus degrades. This degraded product may however compose of free fatty acids, hydro – peroxides and polymerized triglycerides [14].

Due to the temperatures, the physical and chemical of composition as well as the organoleptic structure of the oil changes [6]. An Article by Jha and Das has also mentioned that, in several researches waste vegetable oil based biodiesel showed net energy ratio (NER) of 5-6 compared 0.8 for petro diesel [9].

In many countries, waste vegetable oil is either released into local sewage systems as “ditch oil” or reused in some kitchens. However, In Ghana, the volumes or quantities of waste vegetable oil being generated are not known. Improper management of waste vegetable oils is environmentally unfriendly, it is damaging especially on surface water bodies and aquatic lives causing generation of unpleasant stench in the immediate environs where waste vegetable oils have been deposited for some time [14].

Sadly, in Ghana, most people use cooking oils for frying not once but many times. This practice is considered economical, since cost of cooking oils especially refined cooking ones are relatively high. The practice in many restaurants and fast food joints, is that, potato fries, for e.g. is fried by reusing the oil used to fry an earlier batch. It is also common among food vendors selling fried fish, fried yam, fried plantain, fried meat, etc. to reuse the waste oil they generate for frying repeatedly until the oil becomes dark before they discard it or even in some cases the darkened oil used to prepare ‘Shito’ (pepper sauce) [14].

The use of waste cooking oil produced biodiesel minimizes lifecycle carbon emissions by about 80 percent compared to fossil fuel based diesel, according to the Environmental Protection Agency as reported by Jha and Das [9].

Interestingly, Ghana has an energy policy which could give the biofuel industry the support it needs to excel [12]. Waste vegetable oil can be transformed into a usable and cost effective bioenergy fuel, biodiesel, this will reduce our heavy reliance on the usage of fossil fuels ; diesel, petrol, kerosene, coal, LPG [9].

Brazil and the USA have consistently been the leaders in ethanol production with USA overhauling Brazil as the leader in production as well as in consumption. Europe also happens to be the leading global producer of biodiesel, contributing about 80% of global biodiesel production in 2004 [15]

Recently the European Union (EU) set a target of replacing diesel and petrol with biodiesel and ethanol by 10 % ethanol [3]. The USA on the other hand, aims at producing 136,000,000,000 liters of biofuel by 2022. Since these targets were set by governments and the availability of incentives like tax credits, biofuel production has increased.

The Sub-Saharan region of the African continent however lags behind the rest of the world in energy access [15] . In Ghana however, biodiesel can be generated from three main WVO sources, Hotels, Restaurants and traditional [16].

### 1.2 Problem statement

The global energy demand and rate of climate change as a result of GHG emissions from the use of fossil fuels which happens to be the main energy source in the world is exponentially increasing. Not only is fossil fuel environmentally unfriendly, but the reserves will not be available in the nottoo-distant future because our fossil fuels are not renewable and we are consuming at a faster rate.

There is a need therefore for an alternative and bioenergy promises to be a great option.

### 1.3 Aim

This research aims at Assessing the Biofuel Potential on Marginal Lands and Waste Vegetable Oil Resources in Ghana

### 1.4 Objectives

- To assess the suitability of bioenergy crops production on marginal lands in Ghana
- To estimate the potential of biofuels production from marginal lands, waste vegetable oil and lignocellulosics.
- To evaluate the GHG emissions reduction through production of biodiesel and bioethanol

### 1.5 Justification

Ghana among other nations have decided to reduce their GHG emissions. The country compared to other developed countries have relatively few industries. This implies that, our emissions are mainly from our energy generation and transportation sectors which are fossil-fuel dominated. The government has a biofuel policy to facilitate the aim of integrating 20% biofuel in to the transport sector by 2020. Biodiesel from Vegetable Waste oil which is widely available across the country with no definite end as well as from energy crops cultivated on marginal lands will reduce our load on fossil fuel. Assessing the Biofuel Potential on Marginal Lands and Waste Vegetable Oil Resources in Ghana will bring to light an alternative energy source suitable for the country and raise awareness for policy makers and other stakeholders the advantages of exploiting the resources. The potential of biodiesel from waste vegetable oil will be known. This will help us know how much we can get as fuel for our vehicles. This when considered, will not only help us achieve our aim of reducing our GHGs as a country, but will be as well be in line with SDG 7; affordable and clean energy, SDG 13; Climate action as the GHG emission reduction will be determined. The economy will also be better since this will reduce importation of fossil fuels and jobs will be created.

## 1.6 Scope of work

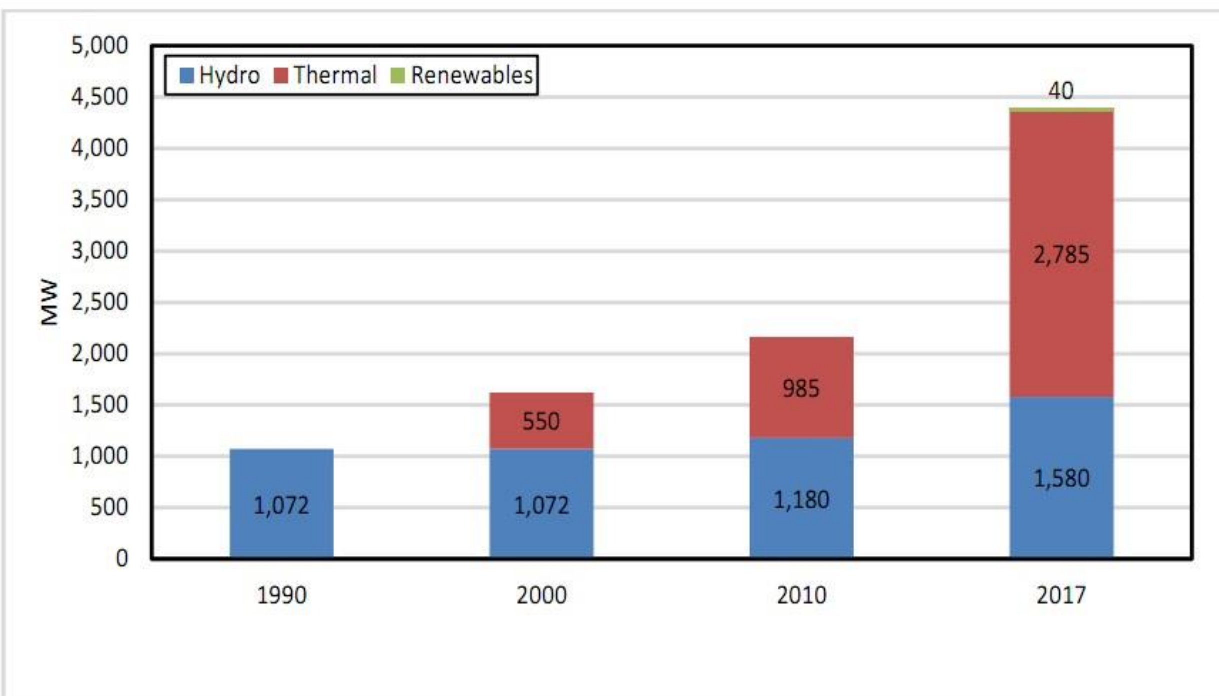
Since the project aims at assessing the potential of biodiesel from bioenergy crops such as jatropha, neem, etc and from waste vegetable oil in the Ghana. Data on daily waste vegetable oil is collected from some households and wayside vendors in some parts of Accra using questionnaires. Information on marginal lands was acquired as well as the soil requirements of some bioenergy crops considered (jatropha, neem, etc,).

# CHAPTER 2

# 2. LITERATURE REVIEW

## 2.1 Ghana's Energy mix

Currently, Thermal energy happens to be the highest in the country's energy mix with a share of a 69.3% as recorded in the 2018 energy report. Hydro which used to be the highest in the mix in the immediate past few years has a share of 30.4% and solar with a negligible share on 0.3% [17]. This is illustrated in Fig 1 below. It is clear that, the thermal contribution to the grid has increased significantly over the years whereas REs (excluding hydro) are of an almost zero contribution, though they have just been exploited in recent times.




NB: Renewables include on-grid, of-grid and mini-grid installations.

Source: 2018 Key Energy Statistics [18]

Figure 2.1: Installed Electricity Generation Capacity, MW

The National Energy Statistics report 2008-2017 has revealed that, Ghana has an installed capacity of 4388MW as at the end of 2017. The dependable capacity is 3971MW and the maximum utilized capacity including exported energy is 2192MW. It is clearly evident that we have an excess capacity of over 1500MW more than our peak load. It is therefore obvious that, one of the main reasons for the current energy insecurity leading to "**dumsor"** is as a result of fuel unavailability [19].

Table 2.2.1: Grid installed capacity, dependable capacity and Peak load (MW)

| | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Installed Capacity** | 1,981 | 1,970 | 2,165 | 2,170 | 2,280 | 2,831 | 2,831 | 3,656 | 3,795 | 4,388 |
| **Dependable Capacity** | 1,735 | 1,765 | 1,940 | 1,945 | 2,045 | 2,487 | 2,577 | 3,363 | 3,521 | 3,971 |
| **Peak Load** | 1,367 | 1,423 | 1,506 | 1,665 | 1,729 | 1,943 | 1,970 | 1,933 | 2,078 | 2,192 |

Source: Energy Statistics 2018 [20]

In our quest to meet our energy needs and ensure energy security, address climate change and other problems such as unemployment the country is currently facing, biofuels seem to be the best alternative which promises to provide the solutions to some of these problems [15]. As it gives us the opportunity to kill two birds with one stone.

## 2.1.0 Fossil fuel Use

The year 2007 was one of the interesting years of Ghana having discovered oil for commercial purposes. As recorded by BBC, the then president of the country, His Excellency Former

President, J. A. Kuffour keenly stated, "with oil as a shot in the arm, we are going to fly" [21]. It is however sad and heartbreaking that, we are not far from where we were then, we are crawling rather than flying since we consume most of the fuel we produce. Fig 2.2 is a chart showing our primary energy production between 20101 and 2017.

According to OEC report, Ghana exported $17.1B, which placed the country as the 70th exporter in the world, exporting several products with gold leading with about 48.7% and crude petroleum the second largest with 17.3% [22]. Should we reduce our fossil fuel consumption we are likely to export more and this will boost our economy.

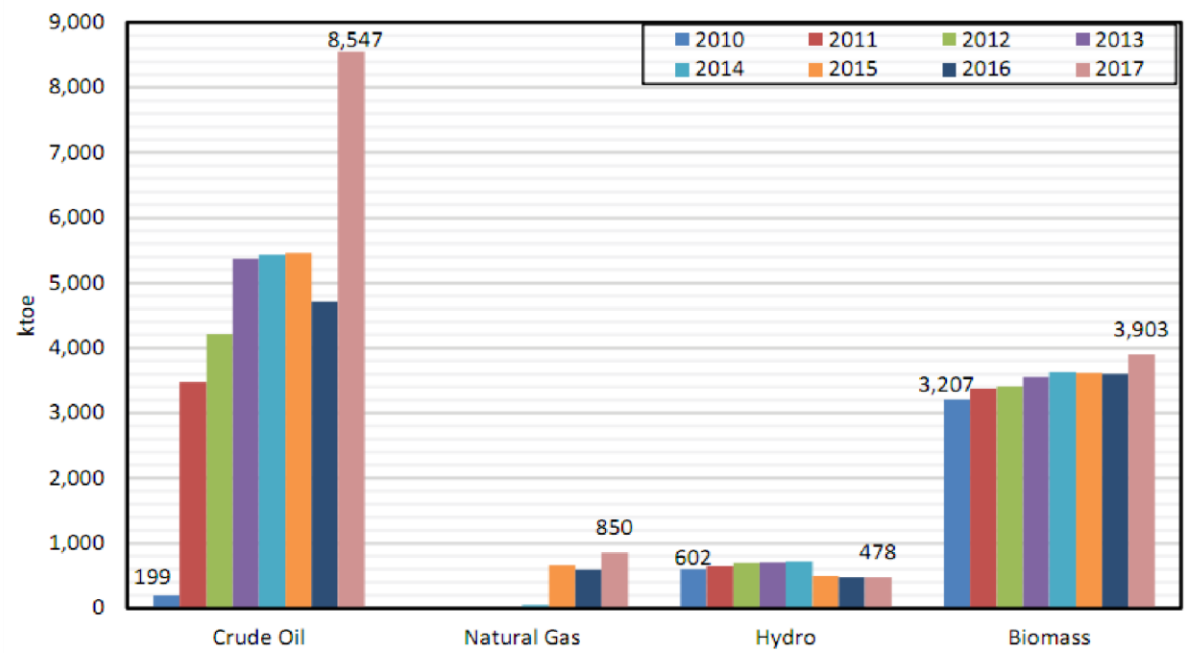



Figure 2.2: Production of Primary Fuels, 2010 - 2017

Source: 2018 Key Energy Statistics [18]

Figure 2.2 and Table 2.2 illustrates the production of primary fuels over the years and the net import of petroleum products has increased over the years, from about 873.8 in 2008 to 3099.6 kilotonnes in 2017. This poses a great threat as we spend more and pollute the environment as well.

Table 2.2: Production, Net import and Total Supply of Petroleum Products (kilotonnes)

| | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Production** | 1,221.5 | 327.1 | 946.4 | 958.0 | 454.0 | 424.2 | 129.2 | 89.1 | 739.0 | 98.0 |
| **Net Import** | 873.8 | 1,390.3 | 1,051.9 | 1,425.6 | 2,262.6 | 2,731.8 | 3,267.1 | 3,527.8 | 2,615.1 | 3,099.6 |
| **Total Supply** | 2007.1 | 2,511.4 | 2,409.1 | 2,733.4 | 3,205.5 | 3,307.4 | 3,263.1 | 3,524.4 | 3,324.8 | 3,462.9 |

Net Import = Import – Export          Source: National Energy Statistics 2008-2017 [23]

### 2.1.1 Energy for transportation

Transportation has a very critical part in the industrialization of the economy [24]. Ghana's transport sector like most African countries mainly depends on the road transport, this results in high need for diesel and petrol [15]. Road transport accounts 96% of passenger and freight traffic in the country and about 97% of passenger miles [25]. It is scary as road transport happens to be the highest emitter of CO2 which is the most important GHG. Figure 3, gives a pictorial presentation of the various means of transport and their contribution [26] [27]. About 80 % of all petroleum products consumed in the country constitutes petrol and diesel. Antwi et al revealed in an article that, the annual diesel demand is growing at a rate of 5%. Combustion of petroleum products and fuels, especially diesel and petrol which are largely used as transport fuels are attributed to as a contributor to climate change as a result of CO2 emissions. As reported by Santos, in 2014, the transport sector globally was responsible for 23% of total $CO_2$ emissions from fuel combustion and road transport was responsible for 20% of it [27]. As shown in Figure 4, the transport sector can be seen as one of the major contributors of CO2 emissions. The drought which led in the energy crises Ghana experienced between 2006 and 2007 is said to have been an effect of climate change [15].

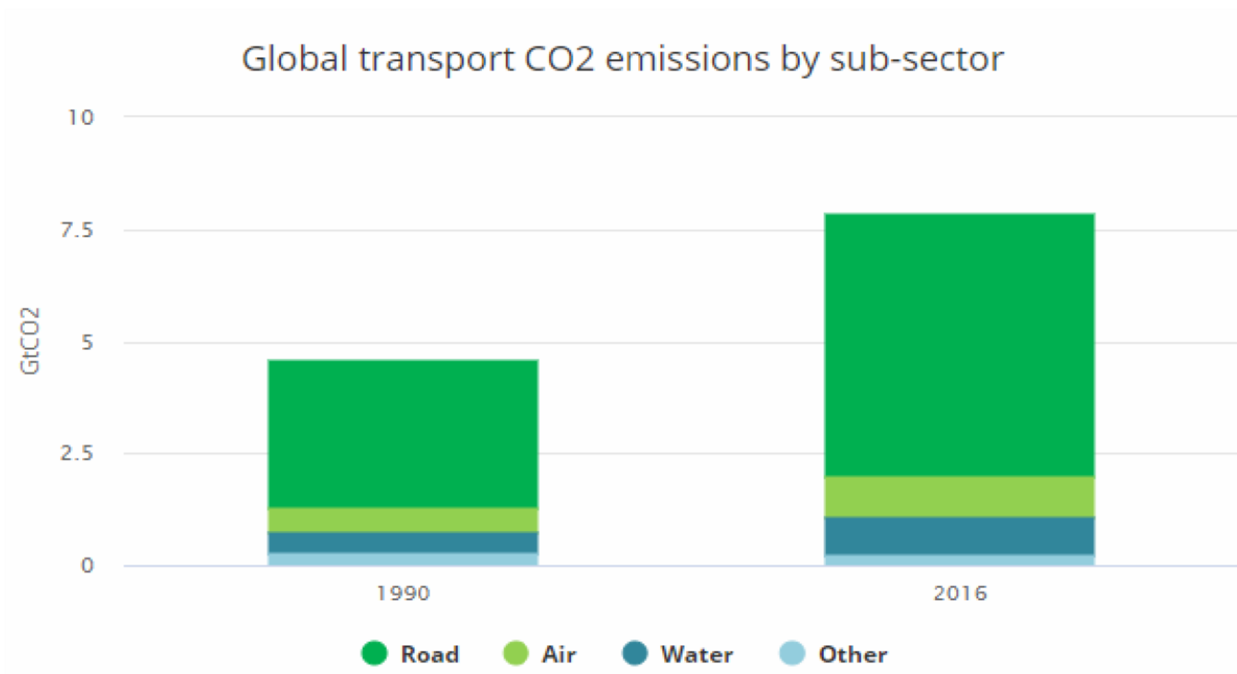



Figure 2.3: Global transport CO2 emissions by sub-sector

Source: IEA [26]

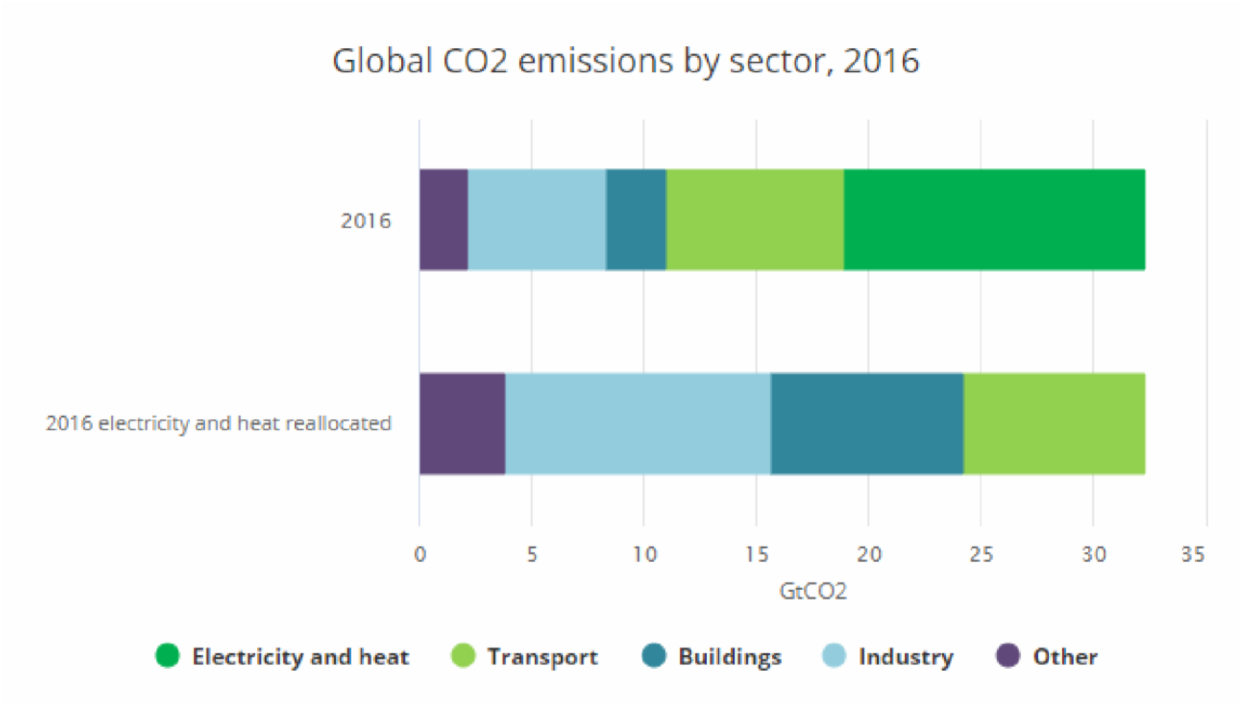



Figure 2.4: Global CO2 Emissions by sector

Source: IEA [26]

A Bus Rapid Transit system named "Aayalolo" buses which was introduced in 2016 came to a barely 2.5 years after it was introduced [28], about 150 of these "Aayalolo" buses were grounded due to lack of funds for fuel purchase among other reasons [29]. Using biofuels, which could have been more affordable and reliable due to the use of local products.

In a quest to minimize the money used on fuel and carbon footprint the school. The Dallas district school is changing all its buses, about 1,700, to operate on an engine that can utilize both biodiesel and processed waste vegetable oil that will donated by the local restaurants. The first bus took to the road in 2009. It is projected that the project will annually save $400,000 by running the entire fleet on the biofuel [30].

In Table 3 below, as reported in the Statistics Energy, The transport to seen to have being the highest dependent on petroleum products, taking more than 50% of the total final energy consumption of petroleum. Transport consumes 2,526.5ktoe of the total final energy consumption of petroleum of 3,086.2ktoe.

Table 2.3: Energy Balance, 2017 (ktoe)

| SUPPLY AND CONSUMPTION | Crude Oil | Natural Gas | Petroleum Products | Biomass | Solar | Hydro | Electricity | Total |
|---|---|---|---|---|---|---|---|---|
| **Final energy consumption** | **-** | **28.8** | **3,086.2** | **2,829.4** | **-** | **-** | **1,039.8** | **6,984.2** |
| Residential | - | - | 176.3 | 2,481.4 | - | - | 532.5 | 3,190.2 |
| Industry | - | 28.8 | 291.1 | 223.5 | - | - | 264.1 | 807.5 |
| Commerce & Service | - | - | 16.5 | 124.5 | - | - | 242.5 | 383.5 |
| Agriculture & Fisheries | - | - | 75.1 | - | - | - | 0.3 | 75.4 |
| Transport | - | - | 2,526.2 | - | - | - | 0.5 | 2,526.7 |
| Non Energy Use | - | - | 0.9 | - | - | - | - | 0.9 |

Source: Energy Statistics [23]

Ghana's quest to exploit its biofuel potential is a great move but will only be fruitful when there is a need for the commodity. Government can however create conditions to make the development of biofuel sustainable as such conditions can cause demand of the commodity to increase as incentives and other tax freedoms are introduced for biofuel markets [31]. This is one of the numerous benefits of the proposed bioenergy policy. Looking at the trends in the above tables, we can conclude there is a need for an alternative energy, a cleaner and sustainable source biofuel is a promising option.

## 2.2 Bioenergy Resources

Ghana is a predominantly an agricultural country with appreciable experience in the cultivation of cash crops such as cocoa [31]. About 60% of Ghana's agricultural lands are still uncultivated. Portion of the uncultivated lands should be earmarked to produce biofuel feedstock that address the food-energy nexus. Multi-purpose crops such as oil palm, coconut, cassava, sugar cane, etc. could be promoted on a large scale to support food and biofuel industry [19]. The experience with the cultivation of cocoa should provide key lessons for the cultivation of biofuel [31].

Currently, cocoa one of our main export commodities, though cultivated mainly by individual farmers, the government provides some assistance and marketing support. Presently, like with cash crops, biofuel crops cultivation initiatives in Ghana involve individual farmers, farmer cooperatives and plantation operations [31].

### 2.3 Energy Crops

Energy crops can be cultivated in large quantities just as food crops [32]. Ghana lies within the $\pm 10^{o}$ north or south of the equator which is an ideal location for palm fruit cultivation. The government has taken advantage of this and cultivated about 240,000 ha of land with palm fruit under large, medium and small scale farms [15]. This however is for edible purposes. According to an article by Antwi et al, as of the time of publication of their article, there was a Presidential Special Initiative (PSI) on palm oil which was projected to have about 300,000ha of land of palm fruits plantation. About 100,000 ha had been cultivated already. Fast success was achieved because the government was directly involved. Ghana is a net importer of soybean even though the country produces about 50 MT with a potential to produce about 700,000T annually. Having an extraction efficiency of about 50 % and 100% conversion of vegetable oils into biodiesel in all cases, seed requirement for soybean was found to be 1, 500, 000T and 4,000,000 T in 2015 and 2020 respectively. The requirement for jatropha, coconut and were found to be not too different. Palm oil and palm kernel oil had the lowest seed requirement to meet the national demand by 2015 and 2020. An important thing considering is the land area required to produce these feedstock since all the various oil seeds have different yields per hectare. This is a very legitimate concern especially when the same piece of land used to grow food can be converted to grow energy producing crops [15]. As revealed by John Perritano, Biodiesel run engines are more efficient than gasolinepowered engines [30]. Some energy crops are mentioned below, some however are food sources as well.

 **Palm tree**

Palm oil is pressed out from palm fruit, it is one of the most energy-efficient biodiesel fuels on the market. Diesel engines can run on palm oil biodiesel without modifications. It as well releases less carbon than gasoline.


Figure 2.5: Palm tree and palm fruits

Source: Author’s shot

**Sugarcane Bagasse**

Sugarcane bagasse commonly referred to as bagasse is a residue of cane stalks left over after the crushing and extraction of the juice from the sugarcane. It presents a great morphological heterogeneity and consists of fiber bundles and other structural elements such as vessels, parenchyma, and epithelial cells. It is composed by 19–24% of lignin, 27–32% of hemicellulose, 32–44% of cellulose and 4.5–9.0% of ashes. The remainder is mostly lignin plus lesser amounts of minerals, waxes, and other compounds. Sugar mills generate approximately 270–280 kg of bagasse (50 % moisture) per metric ton of sugarcane. The Brazilian annual production of sugarcane bagasse is currently estimated at 186 million tons of bagasse.

The deployment of the sugarcane bagasse ethanol technology in Brazil is favored because the production process can be annexed to the sugar/ethanol units already in place, requiring lower investments, infrastructure, logistics and energy supply. Besides, the bagasse is generated at the industrial units, and as such free of transportation costs. This is a promising scenario because from each 10 million tons of dry biomass, 600 million gallons of ethanol could be produced, considering the use of its cellulosic part only [33].


Figure 2.6: Image of Sugarcane & bagasse

Source: [34]

- **Azadirachta indica (Neem)**

Azadirachta indica (Neem) tree is a multipurpose and an evergreen tree, it is 12–18 m tall and can be grown either by directly sowing its seed or by transplanting nursery-raised seedlings. It reaches maximum productivity after 15 years and has a life span of 150–200 years. Planting is usually done at a density of 400 plants per hectare. The productivity of Neem oil mainly varies from 2 to 4 t/ha/yr and a mature Neem tree produces 30–50 kg fruit. The seed of the fruit contains 20–30 wt% oil and kernels contain 40–50% of an acrid green to brown colored oil [35].


Figure 2.7: Neem tree

Source: Author’s shot

- **Jatropha**

Jatropha curcas L. which is also known as the physic nut, is a fast growing bush and is well performing when there is no water. 40% of its seeds is oil. It has been said that the global reliance on crude oil can be minimize with jatropha as it has been found to be a promising alternative RE source since its process of growing, oil extraction and use contribute to sustainable development. Jatropha seeds, according to Ofori – Boateng and Teong, yields 1-4 tonnes of oil and 2.12-12 tonnes per hectare when rain-fed and when irrigated respectively. Jatropha has a lifespan of 50 years and performs great even on land destroyed by pest sand drought. O&M cost for jatropha oil extraction is minimal, in 2010, the period during which Ofori-Boateng conducted a research, it was realized that jatropha biodiesel and petroleum diesel were estimated to US$0.99/liter and US$1.21/liter respectively. This makes Jatropha best option for use as biodiesel to offset the load on fossil fuels and reduce the GHG emissions [36] [37].


Figure 2.8: Jatropha Curcas

Source: [38]

- **Soybean**

Soybean, belongs to the legume and hence has the ability to meet its nitrogen needs from the atmosphere. Temperatures between 25.6 – 30 °C are considered favorable for soybean growth. In the USA, soybean oil is the highest source of biodiesel. It is best cultivated in warm and moist climates does not really have need for intense care, as it is capable of enduring hard conditions. It is able to grow even in minimum agricultural inputs and require little management [39]. Automobiles can run on pure biodiesel or a blend of biodiesel and petroleum. Several researches, including the National Academy of Sciences of the USA have proved soya biodiesel is more environmentally friendly. It also revealed that, less energy is required to convert soya beans into biofuel, also it requires less fertilizer use and is less pollutant. However, more land is devoted to soybean cultivation than other oilseed crops. Its oil content is however not so much. Soybean has oil content of 20%, canola has 40% and sunflower also, 43% [39] [40]


Figure 2.9: Soybeans

Source: [41]

- **Cassava**

Cassava (*Manihot esculenta Crantz*) is a crop that produces edible starch-reserving roots which have long been employed as an important staple food for millions of mankind as well as animal feed. Due to the fact of ease of plantation and low input requirement, cassava is mostly cultivated in marginal land. Cassava is well recognized for its excellent tolerance to drought and capability to grow in impoverished soils. The plant can grow in all soil types even on lands with marginal quality. Considering its availability and affordability in the country it is rational we produce ethanol from cassava. The third largest source of carbohydrates for human consumption in the world, with an estimated annual world production of 208 million tonnes. In Africa, which is the largest centre of cassava production, it is grown on 7.5 million hectare and produces about 60 million tonnes per year. It is a major source of low cost carbohydrates and a staple food for 500 million people in the humid tropics.


Figure 2.10: Cassava

Source: Authors' shot

**Sunflower**

Sunflowers do best in soil with lots of water holding capacity, drainage and fertilzer. Sunflower roots grow deep and spread a lot, so they can stand a dryspell every now and then. They usually start to appear within a two week time frame.

They should be completely grown in 80-90 days [42].


Figure 2.11: Sunflower Source:

Author's shot

Table 2.4: Comparison of oil seed crops

| Oil seed | Rainfall mm/yr (low) | Rainfall mm/yr (high) | Average crop yield per hectare | Oil content as % of seed weight | Average oil yield in kg / hectare | Oil yield /mm of water | Time to full maturity | Useful life |
|---|---|---|---|---|---|---|---|---|
| **Jatropha** | 150 | 300 | 2000 | 30% | 600 | 2.67 | 3-4 yrs | 20 |
| **Palm oil** | 1800 | 2500 | 20000 | 25% | 5000 | 2.33 | 10-12 yrs | 25 |
| **Sunflower** | 600 | 750 | 540 | 40% | 216 | 0.32 | 100-120 days | n/a |
| **Soybean** | 450 | 700 | 1105 | 18% | 199 | 0.35 | 100-150 days | n/a |
| **Groundnut** | 400 | 500 | 1015 | 50% | 508 | 1.03 | 100-120 days | n/a |
| **Coconut** | 600 | 1200 | 7800 | 60% | 5000 | 2.33 | 10-12 yrs | 50 |
| **Castor** | 500 | 650 | 1100 | 45% | 495 | 0.86 | 150-280 days | |

Source: [43]

Table 2.5: Comparison of Crops for Biofuel Production: Ethanol

| Ethanol feedstock | Rainfall mm/yr (low) | Rainfall mm/yr (high) | Crop yield (tonnes per hectare) | Ethanol Conversion efficiency (litre/ton) | Gasoline equivalent ethanol yield (litre/hec) | Ethanol yield per mm of water | Growing season (months) |
|---|---|---|---|---|---|---|---|
| **Sugarcane** | 1500 | 2500 | 70 | 70 | 3300 | 1.65 | 10-12 |
| **Sorghum** | 450 | 650 | 1.8 | 390 | 450 | 0.82 | 4-5 |
| **Wheat** | 450 | 650 | 2.6 | 340 | 600 | 1.09 | 4-5 |
| **Bagasse** | n/a | n/a | 18.9 | 280 | 3550 | n/a | n/a |

Source: [43]

## 2.4 Biofuels

Biofuels has been around for ages, it has been there as long as cars have. The Model T designed by Henry Ford was designed to run on ethanol. The diesel engine was originally designed by Rudolf Diesel to run on vegetable oil. Petroleum fuel became more popular due to the cost of biofuel but the times are changing as we consider environmental pollution as well as the unrenewable nature of fossil fuels. Biodiesel has an energy content of about 90% that of petroleum diesel, bio ethanol is about 50% of ethanol. Most biofuels are as energy dense as coal, but releases lesser carbon dioxide when combusted [44]. Biofuel is fuel whose energy is obtained from biological fixation of carbon. Biological carbon fixation takes place in living things. The difference between biofuel and fossil fuel is period of carbon fixation. It is over a very short period in biofuel, in months or years. Whereas in fossil fuel, it takes over thousands or millions of years. Also, fossil fuels are made entirely of hydrogen and carbon atoms while biofuels contain carbon, hydrogen, and oxygen [44]. Biofuels can be biodiesel, biogas, bioethanol, etc. for the purpose of this study we will look more into biodiesel and briefly ethanol. Biofuel sources are classified as 1$^{st}$ Generation, 2$^{nd}$ Generation and 3$^{rd}$ Generation. 1$^{st}$ generation biofuels also known as conventional biofuels are from sources that food products e.g. Corn, cassava, wheat, palm oil, soya bean oil, etc. They are basically biofuel from feedstock that can be consumed by humans. The 2$^{nd}$ generation referred to as advanced biofuel, preferred because of its feedstock sustainability. This is defined by availability, impact on GHG emissions, impact on land-use and the potential to threaten food supply. Second generation biofuels are from non-edible feedstock; mainly lignocelluloisic biomass like switch grass, corn stalks, etc. No second generation biofuel is also a food crop, although some food products can become second generation fuels when they are no longer useful for consumption.  This generation refers to any biofuel derived from algae. These biofuels are given their own separate class because of their unique production mechanism and their potential to reduce the food versus fuel and land versus fuel debate when biofuel is considered [44] [45]. Some advantages of non-edible oils, which are 2$^{nd}$ generation crops include:

- ✓ The main advantages of non-edible oil are their liquid nature portability, ready availability, renewability, higher heat content, lower sulfur content, lower aromatic content and biodegradability.

- ✓ Non-edible oil feedstocks can be cultivated on marginal lands and in lands of low fertility and moisture demand.
- ✓ They can be grown in arid zones
- ✓ They have the potential of restoring marginal lands.
- ✓ They do not compete with existing agricultural resources.
- ✓ They provide a solution to the competition for food argument.
- ✓ They are more efficient and more environmentally friendly than the first generation feedstocks.
- ✓ Non-edible oil crops can be grown in poor and wastelands that are not suitable for food crops hence less farm land is required.
- ✓ Most of non-edible oils are highly pest and disease resistant.

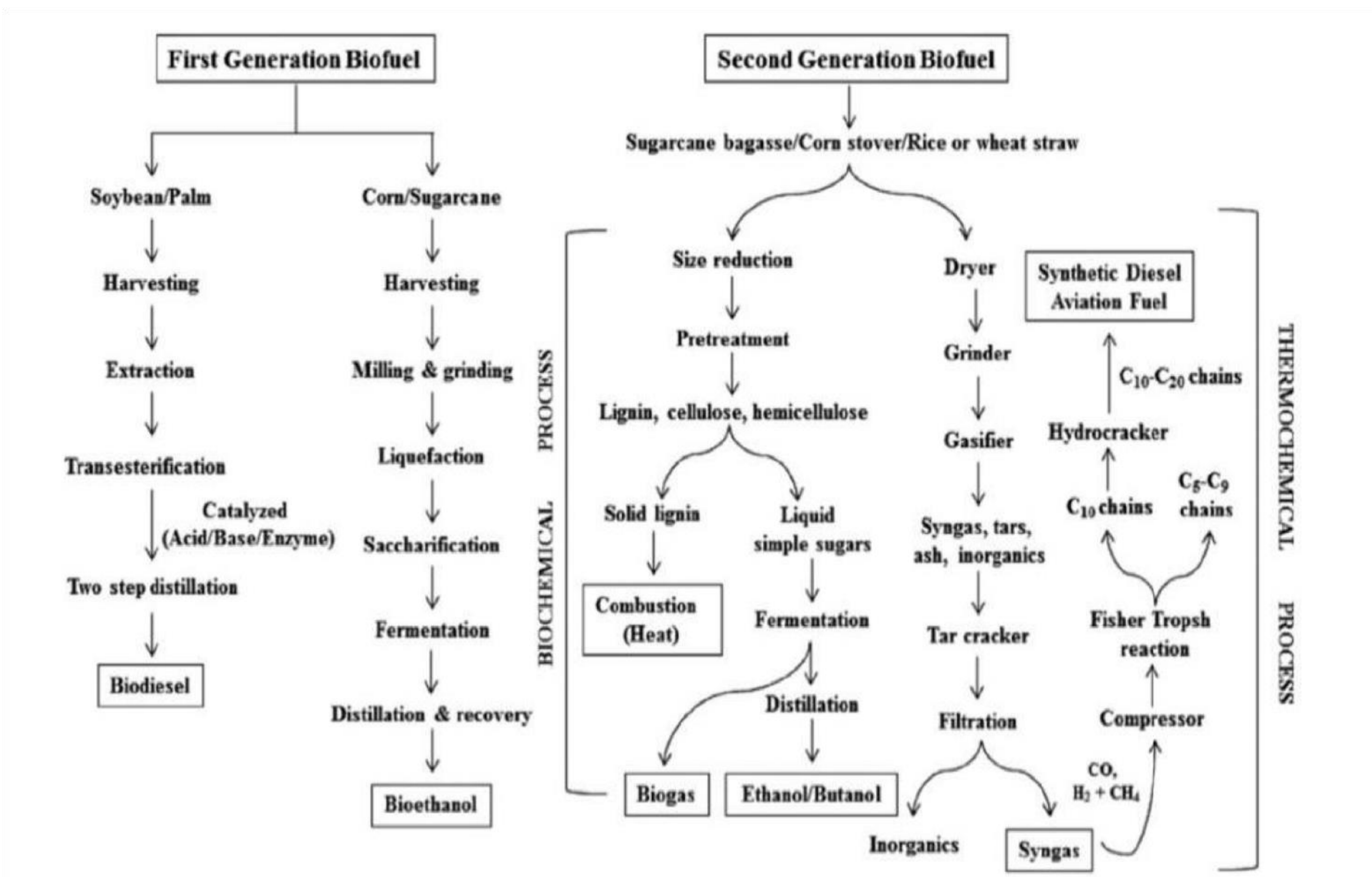



Figure 2.12: First and second generation biofuels

Source: [46]

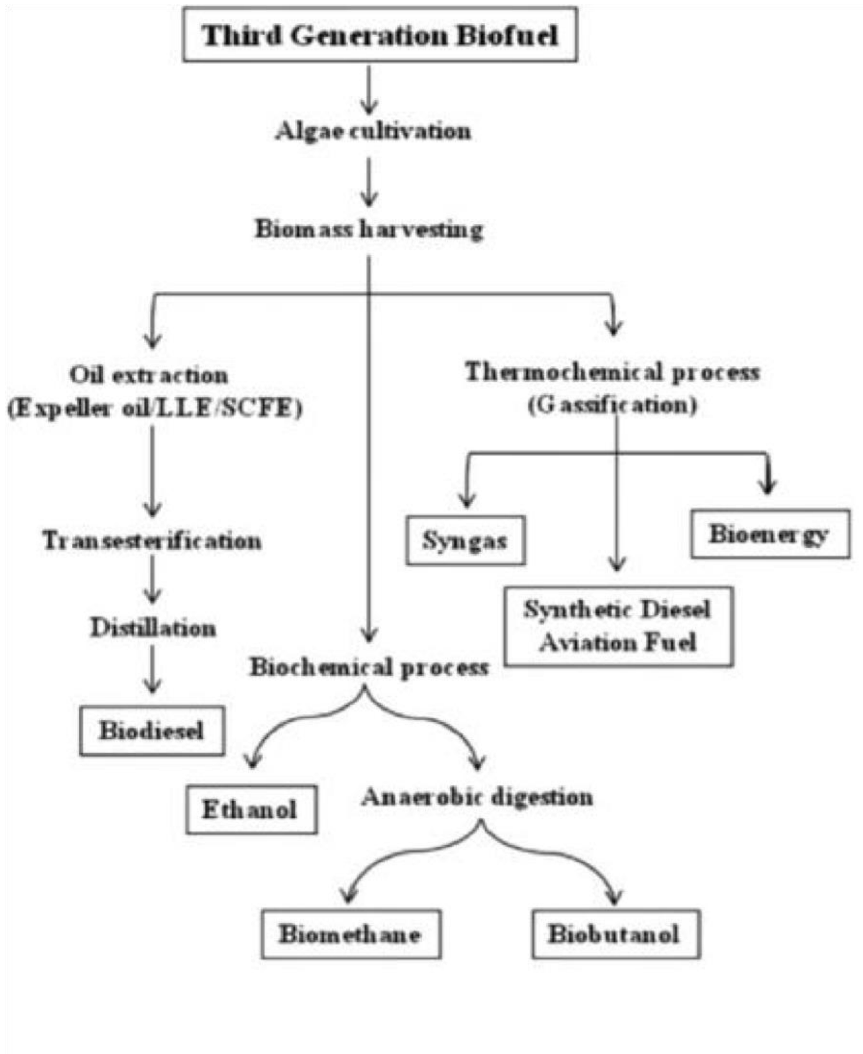



Figure 2.13: 3rd Generation biofuels

Source: [46]

There are several types of bioenergy crops: (a) energy plants for bio-ethanol, mainly plants with high saccharide, starch and fiber content; (2) energy plants for biodiesel, especially non-edible oil plants, e.g., Jatropha. [47].

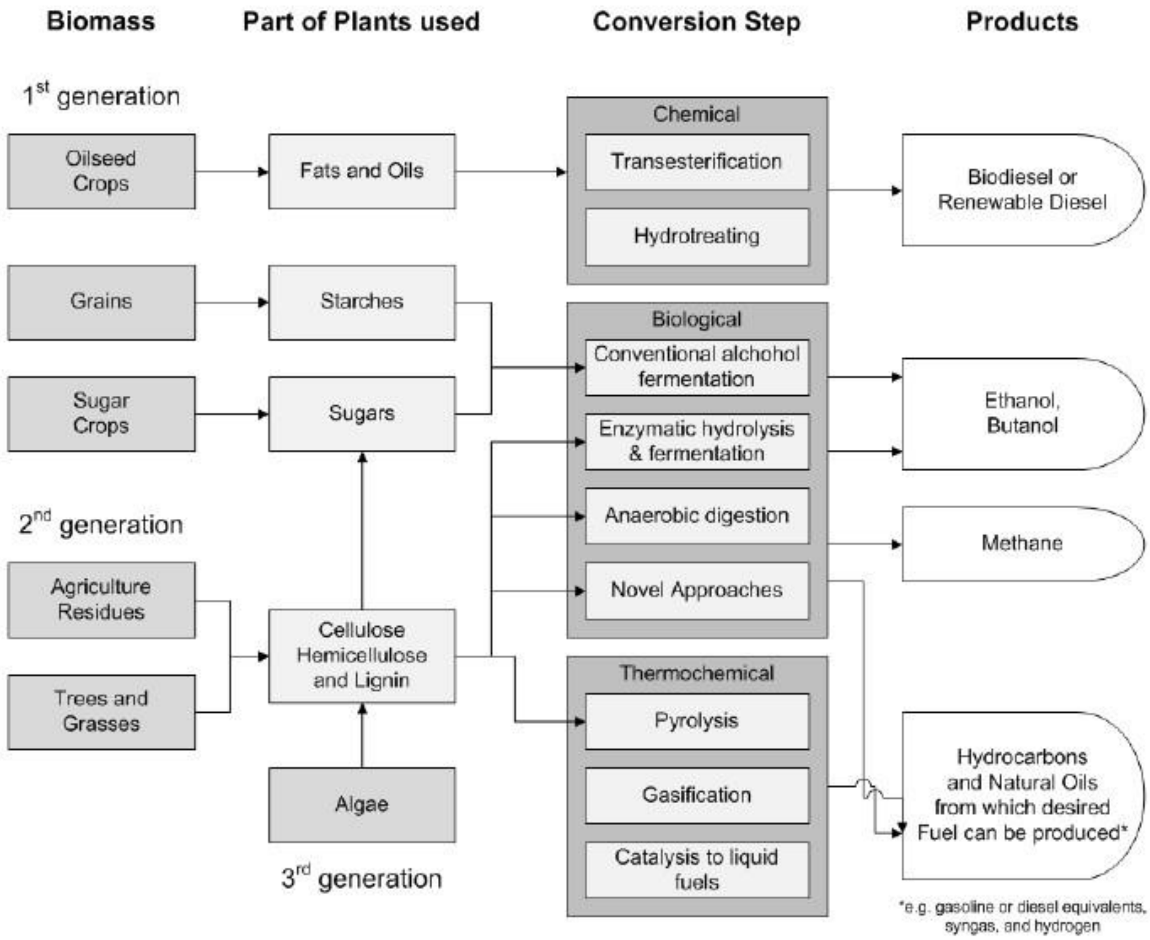



Figure 2.14: Biofuel Conversion Technology (pathways)

Source: [48]

### 2.4.1 Bioethanol

The most famous 1st generation biofuel is ethanol. This is made by fermenting sugar extracted from crop plants and starch contained in maize kernels or other starchy crops [49]. Ethanol has been around from Adam, it as well has numerous advantages, one of which it makes it possible for it to be considered even in this age is it is low-carbon intensity and hence less CO2 emissions. It is also locally cultivated hence reduces reliance on other countries for fuel. Ethanol is cheaper than gasoline. Until we are able to produce a significant amount of electric vehicles that run on renewably-produced electricity, Biofuels are at the moment the seemingly sustainable clean and renewable means of transportation until electric vehicle become widely popular and affordable

[50]. Bioethanol is made from fermentation of carbohydrates produced in sugar or starch crops such as cassava, corn, wheat, sugarcane, etc. Cellulosic biomass, from non-edible sources such as trees and grass are being developed as bioethanol feedstock. Ethanol can be used in its pure form as fuel for vehicles but used as a blend with gasoline to increase octane and improve emission [51].

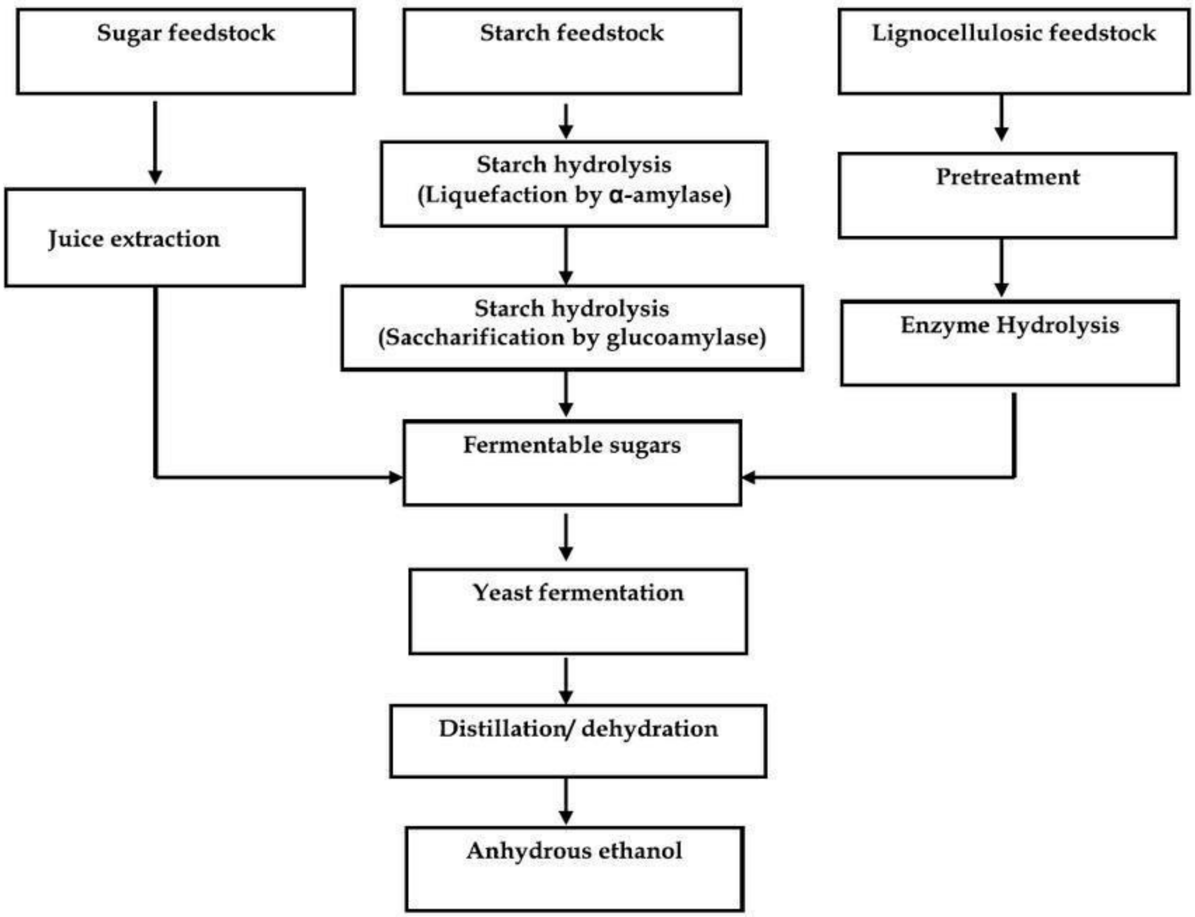



Figure 2.15: Process flowchart of bioethanol production

Source: [52]

Table 2.6: Comparison of ethanol feedstock

| Crop | Yield (tonne/ha/year) | Ethanol conversion rate (l/tonne) | Yield (l/ha/year) |
|---|---|---|---|
| Cassava | 40 | 150 | 6000 |
| Sugarcane | 70 | 70 | 4900 |
| Corn | 5 | 410 | 2050 |
| Wheat | 4 | 390 | 1560 |

Source: [53]

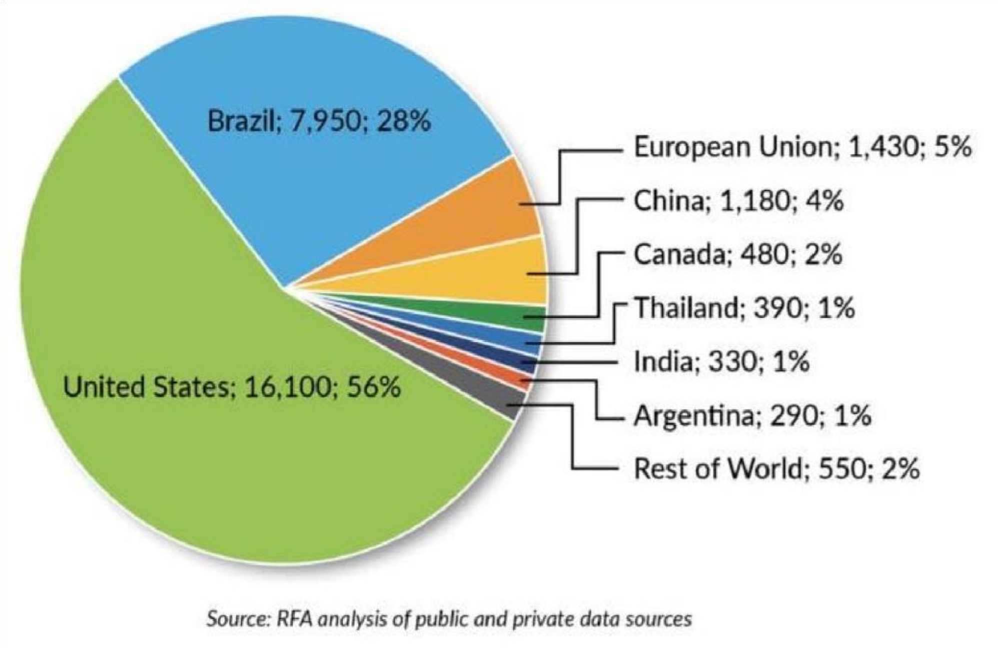



Figure 2.16: 2018 Global fuel ethanol production by country (Country, million gallons, share of global production)

Source: [54]

2.4.1.1 Bioethanol Production Technologies

The biochemical process of converting biomass to bioethanol involves three main processes; Pretreatment, enzymatic hydrolysis and fermentation [55].

**Pretreatment**

This process is to disrupt recalcitrant structures of cellulosic biomass to make cellulose more accessible to enzymes that convert carbohydrate polymers into fermentable sugars [55].

**Hydrolysis**

This is the breakdown of starch molecules into simple sugars prior to fermentation. This process can be made faster by introducing enzymes / acid [56].

**Fermentation**

It is a metabolic process in which an organism converts a carbohydrate into an alcohol. The most use organism (yeast) in the process is the Saccharomyces *cerevisiae*

2.4.1.2 Bioethanol Feedstock

**Starch feedstock**

For ethanol production, starch is a high yield feedstock, starch has to be hydrolyzed using an enzyme α-amylase by fermentation to produce ethanol. E.g. of starch feedstock include; cassava, wheat, sorghum, etc.  Starch is a polymer made up of long chain of glucose units [57].

**Sugar feedstock**

Sugar feedstock such as; sugarcane, sugar beet, sweet sorghum, etc. Sugarcane juice or molasses is the main feedstock for producing ethanol [57].

**Lignocellulosic**

Lignocellulosics are the most abundant biopolymers on earth and can be used as feedstock for bioethanol production. It forms about 50% of the world's biomass [57]. Lignocellulosic feedstock are divided into three categories; agricultural residues, crop residues, sugarcane bagasse, forest residues, and herbaceous & woody energy crops.

- Agricultural residues

A wide range of agricultural residues (e.g. corn stover, straw, wheat straw, bagasse, etc.) can be used for production as feedstock for 2nd generation biofuels. These biofuels are generally considered sustainable as they use waste materials from food crop production, and do not compete with food crops for land. Agricultural residues can be made useful via a number of conversion technologies. E.g., agricultural residues to cellulosic ethanol can be achieved via the biochemical pathway, that is, pretreatment, hydrolysis and fermentation. The residue can also be gasified to form syngas which can further be converted to a liquid fuel using catalysts.

- Forestry residues

Forest residues can also be converted to biofuels by means of thermo-chemical pathways.

- Herbaceous/woody energy crops

A number of energy crops has the potential to grown marginal land to provide feedstock for biofuels production. Energy crops, particularly perennial grasses (Miscanthus, switch grass, prairie grass and short rotation forest species, e.g. Eucalyptus, Poplars and Robinia) are being considered in some countries for this purpose. These crops, when conditions are favorable are high yielding and hence can be harvested over long seasons to provide a steady supply processing plant, thus avoiding costly storage of large biomass volumes for several months between harvests. [49].

Due to the resistant characteristics of its terrestrial plant cell wall, which evolves to form a barrier against external intrusion and degradation, lignocellulosics are recalcitrant. This makes it very involving and difficult to break down lignocellulosics to produce biofuel (ethanol) [58].

### 2.4.2 Biodiesel

As diesel said before, “The use of vegetable oils for engine fuels may seem insignificant today but such fuels may become in course of time as important as petroleum and coal tar products as of present”. This statement has caught up with us, we are in times where biodiesel has become the best candidate to replace fossil fuels [59]. Biodiesel is a clean and hence environmentally friendly fuel. It is produced by trans–esterification of oils from diverse sources. Biodiesel, being fat from life (living organisms) contains fatty acids [60]. It is produced by adding alcohol to the oil which contains triglycerides in a process known as trans-esterification [7] [51]. Biodiesel has been accepted in Europe and is used in diesel engines mostly blended at a % with petroleum diesel [61]. Table 2.7 shows the properties

Table 2.7: This table compares the chemical and physical properties between diesel and biodiesel blends per ASTM standards

| Biodiesel Blends | Density at 15.56 °C, kg/m$^3$ ASTM D-4052 | Kinematic Viscosity at 40 °C, mm$^2$/s(cst) ASTM D-445 | Flash Point, °C ASTM D-93 | Heating Value, kJ/kg ASTM D-224 | Cetane Number ASTM D-13 |
|---|---|---|---|---|---|
| Diesel oil | 829 | 2.8 | 75 | 42,000 | 45 |
| Jatropha biodiesel (B20) | 845 | 5.2 | 88 | 40,000 | 53 |
| Jatropha biodiesel (B10) | 835 | 3.5 | 83 | 41,500 | 48 |
| Palm biodiesel (B20) | 835 | 2.82 | 71.5 | 41,206 | 60 |
| Palm biodiesel (B10) | 833 | 2.49 | 69 | 41,780 | 51 |
| WCO biodiesel (B20) | 855.8 | 2.98 | 60 | 43,953 | 60.71 |
| WCO biodiesel (B10) | 856.4 | 2.85 | 69 | 47,021 | 59.53 |
| Algae biodiesel (B20) | 843.8 | 4.8 | 90 | 37,866 | 70 |
| Algae biodiesel (B10) | 840.5 | 3.31 | 83 | 40,017 | 56 |

Source: [62]

2.4.2.1 Production Technologies

**Esterification**

It is a chemical reaction between carboxylic acids and alcohol in the presences of an acidic catalyst. This process is used in biodiesel production when we have feedstock (oil) with increased FFA content. Esterification converts the FFAs to esters. This is done using strong acids like Sulphuric acid ($H_2SO_4$).

**Triglycerides + FFA (>4%) + Alcohol ⟶ Alkyl esters+ triglycerides**

**Trans-esterification**

This is a major process in the production of biodiesel. It is a chemical reaction between triglycerides and alcohol (methanol) to produce methyl esters and glycerin in the presence of an alkaline catalyst such as KOH or NaOH. If the feedstock (oil) has increased FFAs, such as reused oil, pretreatment or esterification is done before trans-esterification [63] [64].

$$\text{Triglycerides} + \text{FFA} (<4\%) + \text{Alcohol} \longrightarrow \text{Alkyl esters} + \text{Glycerol}$$

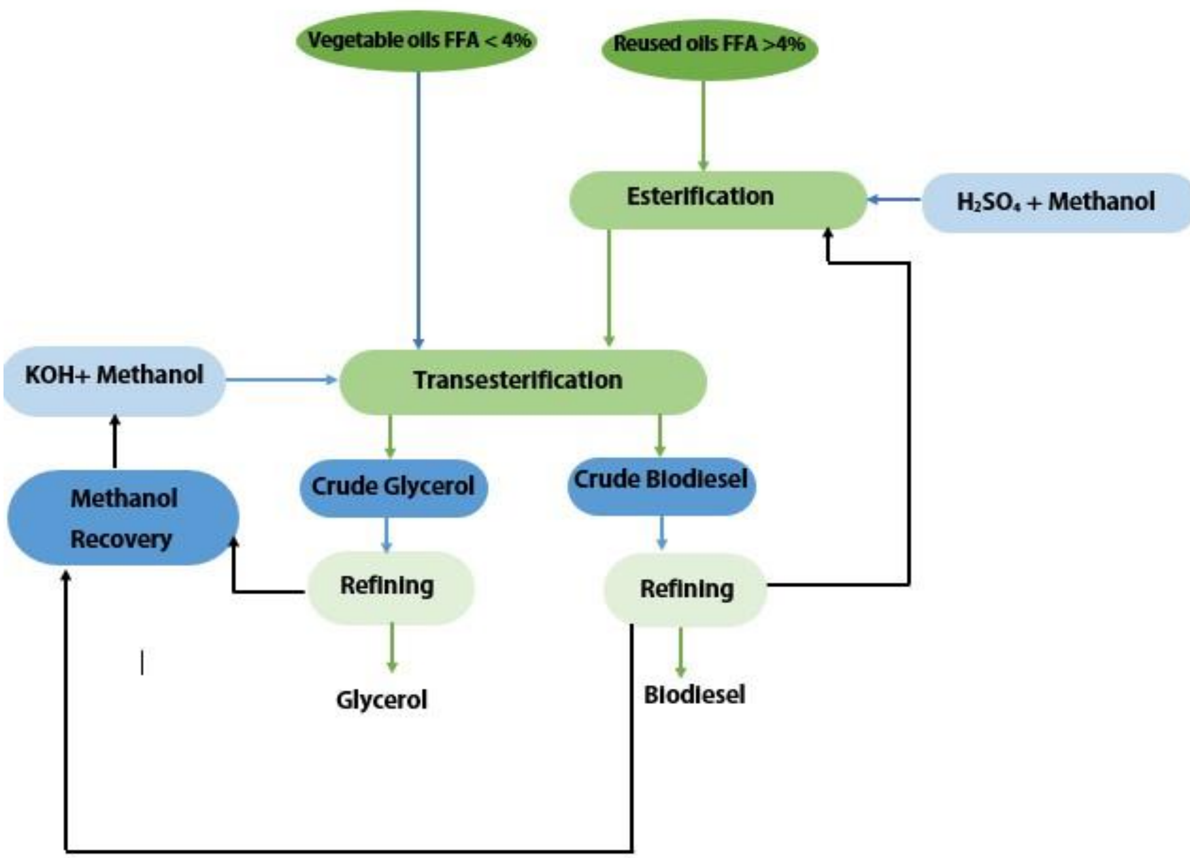



Figure 2.17: Flow Chart of Biodiesel production

Source: Adapted [7] [63] [64]

2.4.2.2 Biodiesel Feedstock

Animal and plant fat are the major sources of biodiesel. Plant fat are used most of the time. Some of these feedstock includes, oil from soya bean, rapeseed oil, sunflower oil, linseed oil, olive oil, palm oil, beef tallow, animal fat, palm nut, coconut oil, etc. Every country and what they can use for biodiesel as some of the crops can only grow in certain countries due to the climate and other conditions necessary for its growth. It therefore makes it possible for almost every country to have a potential biodiesel source [59].in a research by Shirneshan, WVO methyl ester was blended with diesel fuel in 0%, 20%, 40%, 60% and 80% proportions by volume. The blends were prepared just before the experiments. In the tests, WVO was supplied from Modares university biodiesel institute. The lower percentage of biodiesel blends emits very low amount of $CO_2$ in comparison with diesel. After the addition of biodiesel in the blended fuel, HC and CO emissions decrease due to improved combustion with oxygen enrichment of the fuel [65] .

Waste vegetable oils from restaurants etc. are also potential feed stock for biodiesel production. In Ghana and other parts of the world, so much work has been done to determine the potential from this resource which in most cases is just discarded. It has been proved by research that it biodiesel from WVO can be used as engine fuel to run engines with little or no modification. The only challenge with WVO is that, the presence of Free Fatty Acids (FFA) which can reduce the biodiesel yield [60].

Table 2.8: Comparison of fuel property between biodiesel from waste vegetable oil and the standard

| SN | Fuel property | Biodiesel sample | ASTM D-6751 |
|---|---|---|---|
| 1 | Kinematic viscosity ($mm^2/s$, at$40^0C$) | 4.45 | 1.9 -6.0 |
| 2 | Specific gravity (kg/L,at RT) | 0.882 | 0.075-0.840 |
| 3 | Flash Point ($^0C$) | 175 | >130 |
| 4 | Fire Point ($^0C$) | 175 | > 130 |
| 5 | Cloud Point($^0C$) | 12 | -3 to 12 |
| 6 | Pour Point($^0C$) | -2 | -15 to 10 |
| 7 | Copper strip corrosion test 3 h at 50°C | No corrosion | 0.02 |

Source: [60]

Table 2.9: Fuel Properties of Jatropha oil and Diesel

Fuel properties of Jatropha oil and Diesel

| Properties | Unit | Jatropha oil methyl ester (Biodiesel) | Diesel | ASTM D6751-2 Standard | Test Method |
|---|---|---|---|---|---|
| Density | $kg/m^3$ | 880 | 850 | 875-900 | D1298 |
| Viscosity at 40°C | $mm^2/s$ | 4.84 | 2.6 | 1.9-6.0 | ASTM D445 |
| Flash point | °C | 162 | 70 | >130 | - |
| Pour point | °C | -6 | -20 | - | - |
| Cetane number | - | 51.6 | 40 | - | - |

**Source:** [66]

2.4.2.3 Explanation of some terms

**Flash point:** this measure the flammability of fuels the temperature at which a particular organic compound gives off sufficient vapour to ignite in air.

**Pour point:** is the lowest temperature at which a liquid remains pourable at given conditions [67] [68].

**Cetane number:** it is a measure of the ignition quality of diesel fuel. It measure the ability of a fuel to combust under certain conditions of temperature and pressure. The higher the cetane number the faster the engine start and the smoother the combustion. Which means that, combustion is deteriorated with low cetane numbers and hence exhaust emissions of hydrocarbons and particulate. Cetane number increases with increasing length of fatty acids chain and ester groups [66] [67].

**Density**

This is the mass of fuel per unit volume [69].

**Cloud point**

It is the temperature at which a liquid begins to cloud as wax or paraffin begins to precipitate from hydrocarbon solution. This is necessary as solidification of fuels at low temperature can cause blocking of filters and fuel lines [66].

**Viscosity**

It is a measure of a fluids resistance to flow. Fluids can become more viscous in cold temperatures and in some cases solidify. It is there good to know the viscosity of fuels so as to know how good it is to be used as engine oil and at which temperature. High viscosity affect the volume flow and injection characteristics of an engine [70] [66].

2.4.2.4 Factors affecting biofuel production

The food versus fuel and food versus land debate has been one of the main challenges that has hindered the production of biodiesel. The food versus fuel debate has been taken care of to some extent as some energy crops are not edible a common example is jatropha. The challenge with land is also settled as some energy crops can survive on marginal lands. Also, our reliance on the environmentally unfriendly fossil fuels has made biodiesel unpopular until recently when climate change and global warming effects are more obvious. Also, lack of ready market for biodiesel in Ghana at the moment is what stalled jatropha which was to be a major biodiesel feedstock [71].

2.4.3 Biodiesel in Ghana

In 2005, the Energy Commission set up a biofuel policy which was to accelerate the production of biofuel industry in the country. In the November same year, the final draft for the National Biofuel Policy Recommendations, which had an objective of replacing our gasoline consumption with biodiesel by 20% in 2015 and jatropha oil replacing our kerosene consumption by 30% in 2015 [72], none this however was achieved. As at 2015, the reference year for the set targets, biofuels developed was 0 tonnes. However, as tabulated in table 4 below, the government aims at developing at least 100 tonnes by 2020. These can be achieved the challenges however has been; 1. Lack of clear policy on biofuel which is no more the case currently since we now have. 2. The idea of biofuels competing with production of food. 3. Our Land tenure system has over the years posed a challenge to biofuel development as it difficult for investors to have access to large parcels of land at specific locations for investments also 4. Unavailability of logistics for feedstock sourcing [19].

Between 2005 and 2010, jatropha cultivation for biodiesel feedstock was thriving and the acquisition of land for that cause. This was due to the hike in fossil fuel prices on the international market during that period. Most of the investors anticipated there will be a high demand for biodiesel and other biofuel feedstock. The investments were also fueled by international developments such as the Kyoto Protocol among others, which targets promoting the development and use of biofuels and other clean fuels for transport. This made investors assume a ready market for biodiesel and feedstock for biodiesel production [71].

To build a practicable biofuel industry, there must be a sustainable supply of feedstock. The biofuel chain; production, supply and marketing should have fiscal incentives so as to attract any players to make the industry sustainable. Also regulatory mechanisms to monitor entry into the industry and the quality of products should is of great importance. For sustainability, there should be adequate storage and distribution facilities across the nation [31].

Table 2.10: Targets for biofuel development

| **Year** | 2020 | 2025 | 2030 |
|---|---|---|---|
| **Target (tonnes)** | 100 | 5,000 | 20,000 |

Source: Ghana Renewable Energy Plan [19]

To promote biofuel in the country as there is a pressing need presently; we must encourage the use of multipurpose crops such as oil palm, sunflower, etc. for biofuel production. Also, research and development (R&D) in the biofuel field should be supported by the government, so as to ensure more work done especially on 3$^{rd}$ and 4$^{th}$ generation biofuels. A cost competitive market for biodiesel should be created [19]

According to the bioenergy policy drafted in 2010, it was observed that, foreign investors are only interested in seeds after production as they export it for processing and refining. This must be curtailed as we seek to develop the industry as well wish to create jobs and boost our economy. The two years after the publishing of SNEP no concrete steps have being put in place especially by government to meet the set objectives and targets. As stated earlier, B5 and E5 were expected to be introduced voluntarily onto the market by 2008 however this has not come to fruition [15]. We need to develop companies that will take care of processing in large quantities [73].

As the need for other cleaner energy sources arise, environmentalist are pushing for Biofuel is a promising alternative, as it reduces dependence on oil imported hence the import bill. It will as well create jobs and a means of climate change mitigation [73]. To ensure energy security and adequate effectuation, the government issued a policy. The policy issued is to help ensure energy reliability and security, minimization of our dependence on imported oil and which will help decrease the oil import bill. Biofuels development also provide for wealth creation through employment and revenue generation, increase in export earnings and climate change mitigation [73].

As per the Bioenergy policy draft, use of biofuels and the sustainable and commercial production will be encouraged. This is to be done in a way that, there is a balance between land use for traditional cash and food crop production and production of biofuel crops.

The policy also seeks to encourage the use of waste vegetable oils as a feedstock for biofuel production.

The government will as well introduce incentives and favorable pricing means [73].

Local biofuel consumption will be promoted. The institutional framework for boosting biofuel use and production will be strengthened by collaborating with players in the industry.

Exploiting biofuel will Ghana achieve some strategic objectives; increase export earning potential; as the oil we get to export more of the oil generated from the nation’s reserves since biofuel will meet a part of our loads, also jobs will be created and hence the achievement of SDG1, no poverty will be on track, we will have energy security and we will as well reduce our oil imports.

The objectives of the biofuel development program would be to; 1. Substitute national petroleum fuels consumption by 10% and 20% in 2020 and 2030 respectively. 2. To remove institutional barrier to boost private sector engagement in the biofuel industry. 3. To create favorable regulatory climate to ensure development of a competitive market, favorable pricing regime and high quality products. 4. To better the efficiency of production technologies and techniques of biofuel with the aim of reducing costs and also raising the quality and efficacy of the product through prioritized research and development programs; 5. To become a net exporter of biofuel in the not too distant future and 6. To reduce $CO_2$ emissions.

The country's roadmap for bioenergy implementation, in 2010, in September, A bioenergy unit is to be established within the energy commission to organize a stakeholder consultation and development implementation program; this is to provide institutional focus on bioenergy. In December of the same year, a portion of the energy fund each year should we allocated for technical assistance to bioenergy producers/ equipment manufacturers and R&D, this will result in the creation of sustainable funding source for the bioenergy industry. The Energy Commission is the responsible institution for both activities in 2010.

In 2011, most of the activities in the roadmap was expected have been rolled out, from January to March, The Ministry of Energy was to obtain cabinet approval for bioenergy recommendations, this was to result in a Bioenergy policy adopted by the government, June of the same year was to see the establishment of a technical committee with the energy commission to address coordination issues between related institutions like MoFA, EPA, NPA, etc., this is expected to get a dedicated technical committee on available bioenergy. A Bio-fuel policy implementation forum was to be organized in July by the energy commission, this was to sensitize stakeholders on their roles in relation to the biofuel policy implementation. In August 2011, all stakeholders were responsible for biofuel for the full implementation of the policy recommendations. The NPA and the Energy commission in December had to prepare relevant regulations on bio-fuels for Cabinet approval, this is to appropriate the prepared regulations governing the biofuels sector. Research also revealed that, Surveys on biodiesel from jatropha & WVOs have been completed, trans-esterification of samples of oils from the mentioned feedstock are also completed & biodiesel tested for the mileage covered. It is said to be a replacement for fossil fuel [72].

#### 2.4.3.1 Waste Vegetable Oil in Ghana

A study done in five regional capitals of Ghana in 2010, revealed that hotels in these cities generated as much as about 33,840 litres each per month. The research revealed that the main competitors for the use of waste vegetable oils as biodiesel are soap makers, commercial shito (pepper sauce) producers, domestic users and other food vendors [14]. According to Stoytcheva and Montero, reusing fried oil poses a high risk to our health [6]. This waste vegetable oil has a great potential as a feedstock for biodiesel production, considering the litres generated daily from restaurants, hotels, etc. A research conducted by Mensah and Obeng, revealed that hotels in Accra generated the highest quantity of Waste vegetable oils per month. Generating about 35,617 litres, 3,041 litres, 2,205 litres, 2,125 litres, 1,809 litres, from Accra, Kumasi, Takoradi, Sunyani and Tamale [74].

### 2.4.4 Biofuel use in other countries

Since the dawn of civilization, fossil fuel has been used indiscriminately. And this has led to emissions of CO2 which is contributing to climate change. In the 1970s, Brazil initiated the project to replace gasoline by ethanol, this was to minimize the dependence of fossil fuels from politically and economically unstable periods. Sugarcane, was chosen as feedstock in this program to produce ethanol. The country therefore intensified agricultural and technological studies in that regard. This led Brazil to a favorable position in energy security. It must be noted that, not all of the sugarcane produced is used in ethanol production, research revealed that, one-third of the plant is used for sugar production, 1/3 which is bagasse is used for electricity production. The other third is left on the field and is decomposed by microorganisms. The straws, leaves and bagasse can are also potential feedstock for bioethanol production, this can only be possible if technologies are developed to convert the biomass to ethanol. At present, about 80% of vehicles in Brazil run on bioethanol, and they are in the process of developing small airplanes that can run of bioethanol. The major advantage of the production of bioethanol from sugarcane bagasse in Brazil is the use of a residue, almost 10% of the total generation, which is usually rejected and cause environmental problems [33].

According to a research done in Nigeria to determine the potential of Biodiesel in the country the quality of the biodiesel is in total agreement with the ASTM standard, which means larger amounts of waste vegetable oil generated from restaurants and fast food joints on a daily can now be sold to biodiesel producers who in turn will recycle and make it a fuel [10].

The use of biofuels has been of interest to government because of how easy it can be mixed with fossil fuels for use, especially in the transport sector. This increased interest has led to an increase in biofuel feedstock production globally. This has brought about the food versus energy argument [75].

In an article published by Ofori-Boateng and Teong, as reports in some studies in countries like India, Mali, etc. using jatropha oil on commercial basis is cheaper making it economically feasible for production [37].

Southern Africa happens to be the only region in the sub-Saharan African to utilize biodiesel. The South African biodiesel industry is however still you, with waste vegetable oil being its main feedstock. As revealed by Mbohwa et al, at the period of this research, two big biodiesel plants were under construction, booth to use oil seeds as feedstock, soybean and canola seeds. To meet the feedstock needs of the biodiesel plants, a 500 thousand hectare land has been targeted for oil seed production. 250, 000 hectares each for soybean and canola. The plants are to increase the biodiesel production to about 100 million litres per year which can met 1.25% or the countries diesel requirements against the 2% set by the government. Also, currently the biodiesel plants used in SA are batch processors and hence very simple to operate, very little training is needed hence jobs will be created [76].

### 2.5 Land acquisition

In Ghana, district land could be obtained either by inheritance, by lease and private ownership. According to FAO Ghana, in Ghana, about 50% of the farmers acquired their land without any payment, the rest acquire their land through either sharecropping and on a fixed rent basis [77]. Most agricultural lands in Ghana are communally owned. This is managed by lineage or clan – based land owning groups and allocated to individuals or households on a usufructuary basis [78]. At present there are no known laws hindering acquisition of land for energy crop cultivation. Acquiring land is however a private engagement with owners. Owning a land for cultivating biofuel crops is not different from land ownership for cash crops. As a result of the increased interest in alternative energy in our quest to reduce emissions and get cleaner means of meeting our energy needs, demand for energy crops was on the rise, this led to an increase in the rate and scale of acquiring land. This is attributed to as a cause of the 2017/ 2018 global food and economic crises [75]. There is a need to regulate land acquisition for biofuel crop production so as to avoid fertile land for food crop cultivation. Government can empower traditional land owners to facilitate biofuel crop cultivation land acquisition [31] .

Ghana has a total land area of 23.9 million hectares, 13 million ha which is about 54% of the total is suitable for agricultural production. Our Land use can be classified as; forest reserves wildlife reserves, unreserved high forest, savannah woodlands, tree crops, annual crops, unimproved pasture, bush fallow and other uses [78]. Per the bioenergy policy draft of Ghana, acquisition of land for biofuel crops development will conform to the pattern by which land is acquired for cash crops [73] [71].Table 2.10 and Table 2.11 shows tables of land use in Ghana.

Table 2.11: Land Use Area Pattern

| Land Use | ('000) sq.km | % of Total |
|---|---|---|
| ***Agriculture*** | | |
| Annual Crops | 12 | 5 |
| Tree Crops | 17 | 7 |
| Bush Fallow and other uses | 60 | 25 |
| Unimproved pasture | 36 | 15 |
| **Sub Total** | **125** | **52** |
| ***Non Agriculture*** | | |
| Forest reserves | 26 | 11 |
| Savannah woodland | 71 | 30 |
| Wildlife reserves | 12 | 5 |
| Unreserved forest | 5 | 2 |
| **Sub Total** | **114** | **48** |
| **Total** | **239** | **100** |

*Source: Ministry of Food and Agriculture, Medium Term Agric. Development Program (MTADP), (1990).*

Source: [79]

Table 2.12: Land Use (Specific to Agriculture)

| Type of Land Use | Hectares | (%) |
|---|---|---|
| 1.0 Total Land Area (T.L.A.) | 23,884,245 | 100.00 |
| 2.0 Agric. Land Area (A.L.A.) | 13,600,000 | 56.94 |
| 2.1 Area under cultivation (2015) | 6,421,450 | 47.22 |
| 2.1.1 Total area under irrigation (2015) | 221,000 | 3.44 |
| 3.0 Area under inland waters | 1,100,000 | 4.60 |
| 4.0 Others (forest reserves, savannah Woodland etc.) | 8,746,021 | 36.60 |

*Sources: The Ghana Survey Dep't and SRID, MOFA, Accra*

*Note: Percentages will not add up to 100 because Area under cultivation is part of Agric. Land Area, while area under irrigation is part of area under cultivation.*

Source: [77]

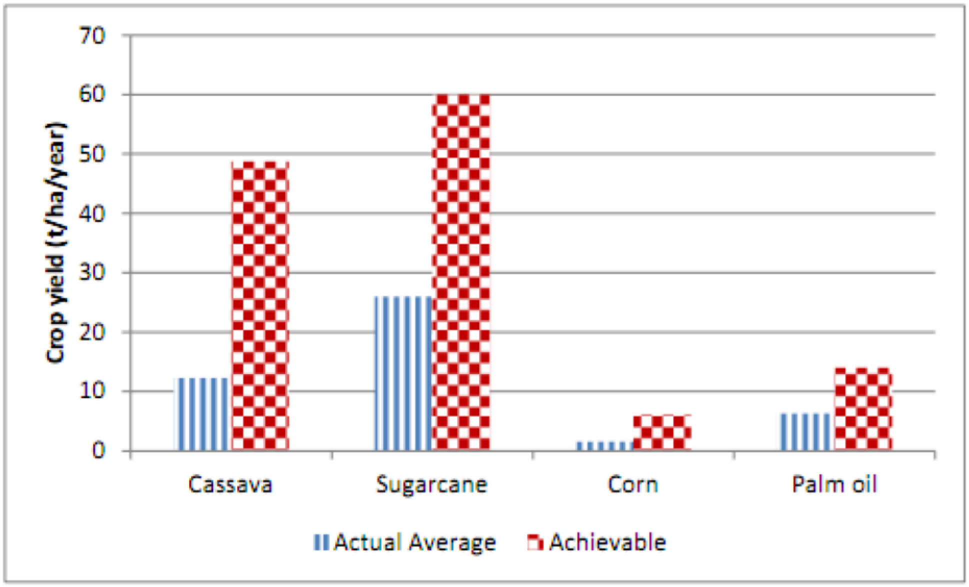



Figure 2.18: Land Use efficiency gap

Source: [53]

### 2.6 Marginal lands

Marginal land, though a common term, is a relative term with no definite definition. Marginal lands are generally as lands with poor soil quality for crop production [80]. Due to its potential to increase food security and support bioenergy, marginal lands have been of great interest and has hence got much attention [81]. According to Rajagopal, Agricultural lands can be considered marginal due to some factors such as: soil fertility, drainage, slope, water availability, poor management practices, and the biophysical nature of the soil [43]. Australia, UK, USA, India, Indonesia, etc. have taken on policies that allow the expansion of biodiesel production on marginal lands [82]. Marginal lands are considered very important for the cultivation of 2$^{nd}$ generation bioenergy crop (i.e., lignocellulosic biomass crops). 2$^{nd}$ generation bioenergy crops gives an appealing alternative for preventing land competition between 1$^{st}$ generation bioenergy crops (e.g. wheat, sugarcane, etc.) and food crops [81]. Some of the factors that render land marginal can be overcome and through restored to productive lands by improving land functions investment in modern technologies such as drip technology, fertilizer and micro nutrient application, etc. [43] [81]. Marginal lands provide potential land resources for food production. Research shows that, 36% of global agricultural lands are marginal, that is about (1.3 billion ha) and this percentage supports about one-third of the global population [81]. In this study, marginal land is defined as land that has relatively poor natural condition but has the ability to produce energy crops [47].

### 2.6.1 Reclamation of mining lands in Ghana

During mining of resources, the topsoil is degraded, as the soil loses its structure and is exposed to excessive erosion, leaching etc. [83]. Many research findings, shows that, Ghana soils are affecting by our small-scale mining activities. A study by Ontoyin et al., has revealed that, small scale mining has affected the lives of populace in mining communities as their activities disrupt their normal lives as farmlands are rendered unproductive among others that affect their livelihoods. Most of people in such communities tend to resolve to reclamation of the lands, etc. in order to survive [84] [83]. Revegetation is one of the most accepted means to improving soil fertility on mined lands [83]. The EPA, Ghana require mining companies to clean up and repair degraded lands after mining through various rehabilitation stages of which revegetation is a part. Reclamation which has been defined as the rehabilitation of areas disturbed by surface or underground mining. This is basically to re-establish the vegetation cover, stabilize the soil conditions [85]. Land reclamation has been one of the main ways we get back our degraded lands, as the EPA has tasked mining companies to reclaim lands after mining, research done by Tetteh et al. indicates that, most people mining communities are satisfied with the results of land reclaimed as they are able to go about their farming activities and other means of earning [86]. Development of bioenergy crops that can withstand the condition on mined lands in order to help in reclamation is a great idea as lands will not only be reclaimed but we as well get feedstock for biodiesel production.

## 2.7 Climate change

The Paris Agreement, which is an international treaty that attempts to minimize GHG emissions. This agreement is United Nations Framework Convention on Climate Change (UNFCCC) sponsored and became took effect on November 4, 2016. This agreement seeks to limit increase in temperature in the present-day to below $2^{o}$C and promote actions that that seek to reduce to $1.5^{o}$C or lower. Ghana is a signatory to the agreement. All countries participating in the Paris Agreement are expected to prepare, communicate and maintain successive nationally determined contributions (NDCs). These contributions include regular reports on gas emissions and efforts and timeframes to reduce them. In our quest to meet the target, the government set NDCs and National Climate Change Policy [87].

Research has shown that, biofuels combust cleaner than fossil fuels, emitting lesser pollutants and GHGs, such as CO2 [30]. The, global CO2 emissions from burning fuel were 32.31 GtCO2, which is similar to levels in 2015. Reminiscing, it is realized that emissions have more than doubled since the 70s and increased by about 40% since 2000. Most of these increases are linked to increased economic output. Despite emissions being relatively stable between 2013 and 2016, initial IEA analysis showed that in 2017 emissions increased by around 1.5%, led by China, India and the European Union [26]. Kemausour et al, revealed that, using bioenergy, will save about 8PJ and 58PJ by 2030 from transportation and electricity generation and 10PJ and 96PJ by 2030, in a moderate and high bioenergy modelling respectively. The article also revealed that, there is a potential reduction in GHG is 3 million tonnes of $CO_2$e and almost 6 million by 2030. That is about, 14% reduction at a projection of about 96% by 2030 in a reference scenario [88]. Argonne researchers' have revealed that, biofuel from energy crops when likened to gasoline can reduce emissions by 101-115 % [50].

It's important to know how much $CO_2$ emissions are created per litre of diesel so you can calculate your overall emissions. Research revealed that, it requires burning 378.92 litres of diesel to emit 1 tonne of $CO_2$ into the atmosphere and burning 340.69litres of petrol emits 1 ton of $CO_2$ into the atmosphere [89].

Also, according to Australia's National Greenhouse Accounts (NGA) 2.33kg of $CO_2$ is emitted for every litre combusted in an engine. The NGA also states that one litre of ethanol reduces net emissions of $CO_2$ by over 99%, so one litre of ethanol will save approximately 2.3kg of $CO_2$.he US EPA estimates that on a Life Cycle Analysis basis, one litre of cellulosic ethanol reduces net emissions of $CO_2$ by over 90.9%, so one litre of ethanol will save 2.11kg of $CO_2$. Australia's National Greenhouse Accounts (NGA) 2.7kg of CO2 is emitted for every litre combusted in an engine. One litre of biodiesel reduces net emissions of $CO_2$ by over 95%, so one litre of biodiesel will save approximately 2.5kg of $CO_2$. One litre of biodiesel reduces net emissions of $CO_2$ by over 95%, so one litre of biodiesel will save approximately 2.5kg of $CO_2$ [90].

### 2.7.1 Ghana's Climate change policy

With the increasing instability in petroleum prices and its supply from the Middle East, many countries have decided to direct their energy policy towards the use of biofuels. This imposes an enormous pressure on the production of crops that can supply bioethanol [33].

Ghana like other countries reached a landmark agreement at COP21 in Paris, has put measures in place to meet targets aimed at reducing GHG emissions. In the quest to meet our targets, the government of Ghana introduced the Ghana National Climate Change Policy Action Program for implementation between the years 2015 to 2020. The climate change policy covers 10 thematic areas. Policy Focus Area 10 of the Policy Action is: Appropriate Energy and Infrastructure

Development (minimizing greenhouse gas emissions)

Under the Policy Focus Area 10; Program 10.5 is Renewable Energy Development Action 10.5.1 of the program 10.5 is to, "Promote the use and more efficient production of solid and liquid biomass fuels with lower net greenhouse gas emissions potential" and the Purpose of action: To reduce non-$CO_2$ emissions in the production and consumption of solid and liquid biomass energy resources. The expected output of this action is reduced non-carbon emission factors in the production and consumption of biomass fuels: this is to limit the growth of greenhouse gas emissions with one of its 6 Objectively Verifiable Indicators which is Renewable energy penetration increased to 10% by 2020.

Under Action 10.5 of the GNDC, there are a total of 10 tasks under this action. 4 out of the 10 is about biofuels which shows the significant contribution biofuels has in reducing Ghana's GHG emissions. Some of these tasks include: supporting the development of biofuel on appropriate and suitable land (e.g. land reclaimed in the mining sector) this is to ensure a potential threat to food security is prevented. Also, to support biofuel development as a substitute for fossil based transport fuel which currently dominates our transport sector. To support private sector investments in the biofuel industry, from cultivation of feedstock to the distribution of biofuel.

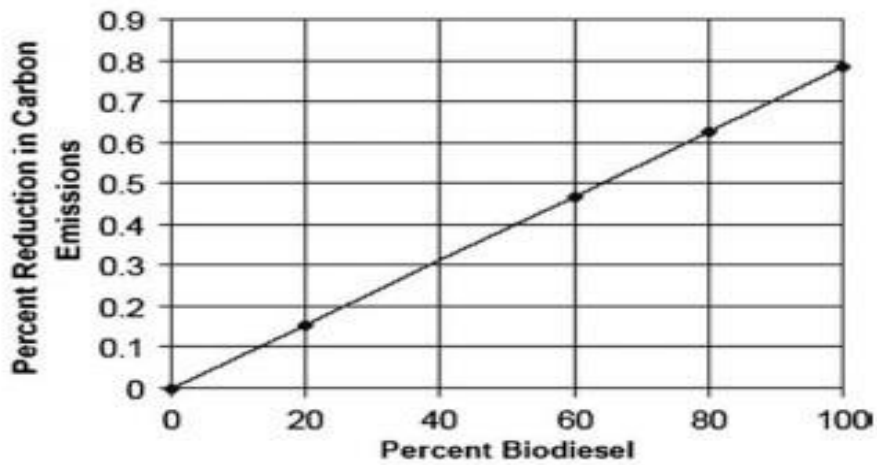



Figure 2.19: Effects of biodiesel blend level on CO2 emissions

Source: [91]

## CHAPTER 3

## 3. METHODOLOGY

### 3.1 Study Area Description

Accra, the capital city of Ghana is the study area for this project is located in West African country that lies above the equator in the northern hemisphere with 16 administrative capitals and a population of about 30,433,858 [92] [93]. Accra, like most capital cities is the most populous city in the country. Recent estimates have shown that, Accra has a population of about 2.27 million [94]. The city shares boundary with Volta region to the east, to the north, the Eastern region, to the west the Central Region and with the Gulf of Guinea to it's the south.  Accra lies at latitude 5.6037 degrees North and longitude 0.1870 degrees West with an elevation of 61m (200ft) above sea level. [95].  For the purpose of this study, in determination of biodiesel potential from households and wayside vendors, Osu, Labone, Labadi, Cantoment, Nyaniba estates,Asylum down, Amasaman and Ashongman were considered, but, the whole of the country was looked at in the determining the potential of bioenergy crops on marginal lands.

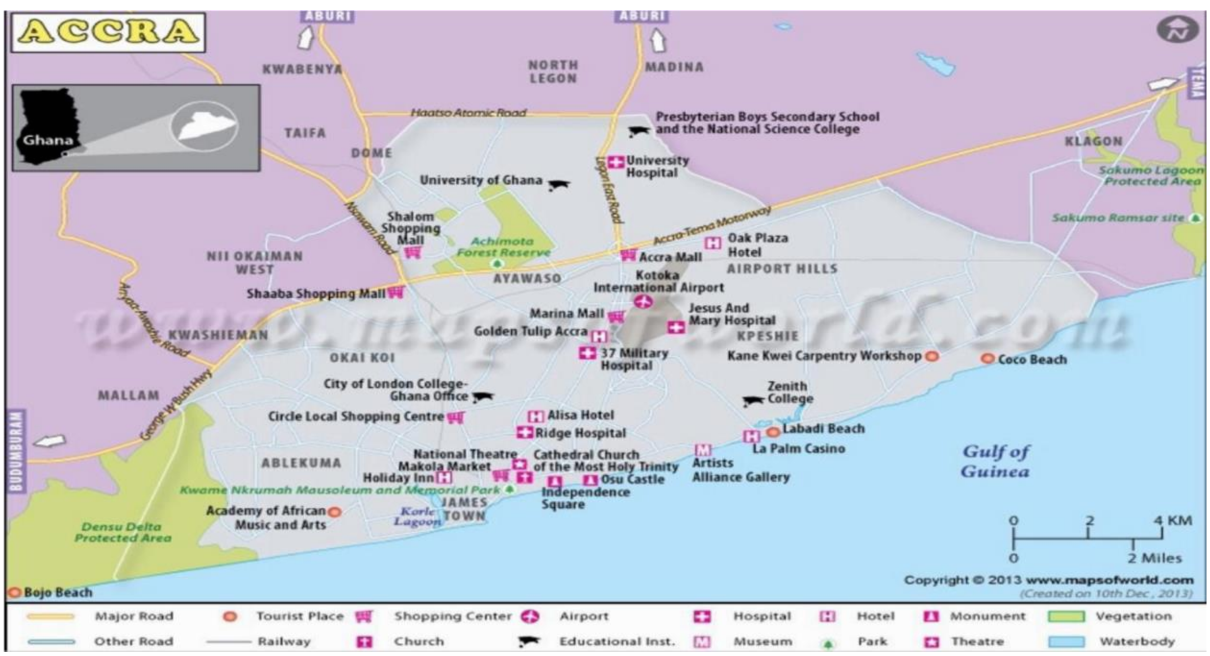



Figure 3.1: Map of Accra

Source: [96]

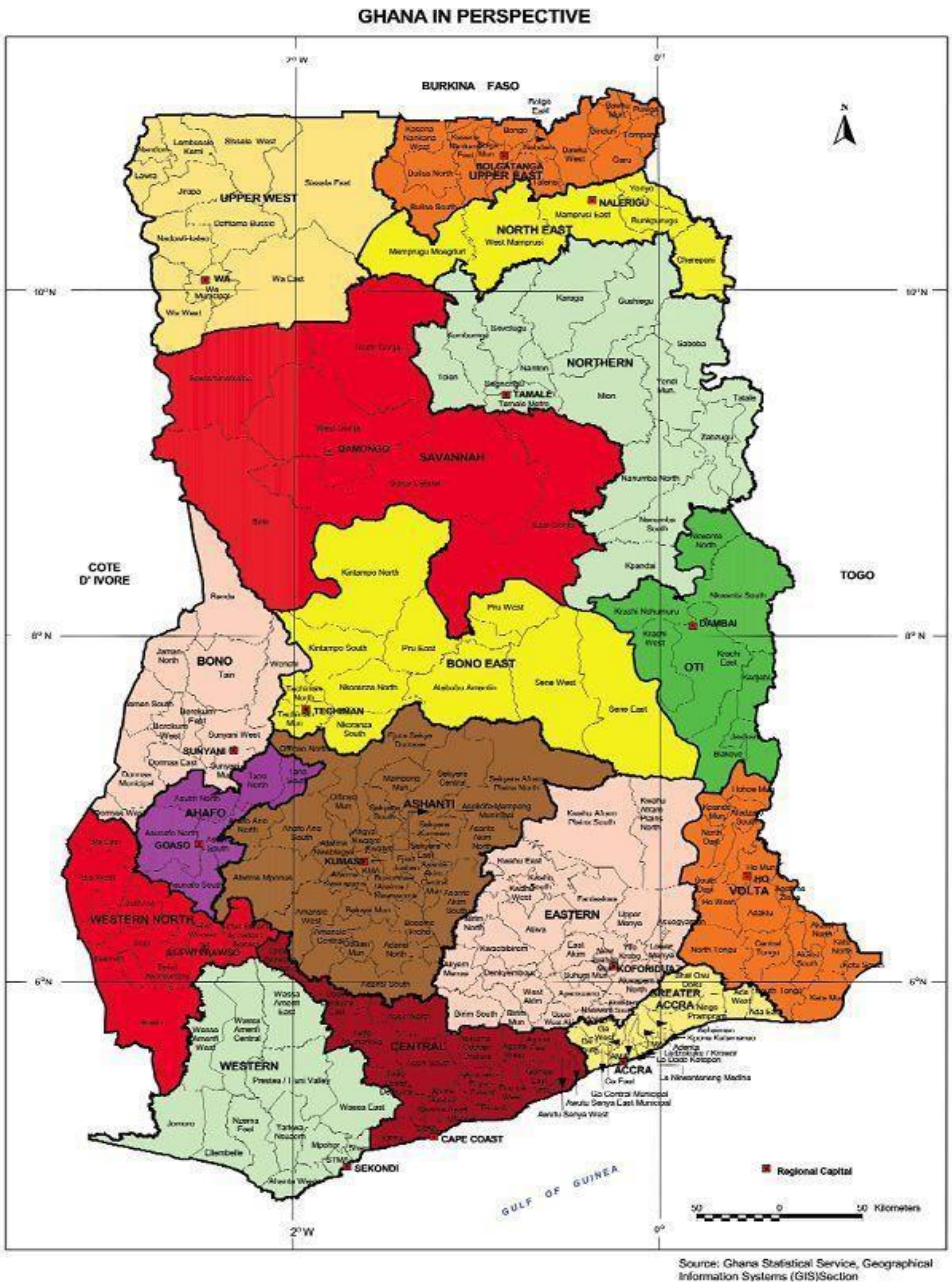



Figure 3.2: Map of Ghana

Source: [97]

**Interviews were conducted on the following**

- Waste Vegetable Oil generation
- Uses of waste vegetable oil
- Quantity of Waste Vegetables Oil discarded

Table 3.1: Data collected for determining potential of biodiesel from WVO

| **Questionnaire** | **Number of Respondents** |
|---|---|
| 1. Potential of WVO from households for biodiesel | 101 |
| 2. Potential of WVO from wayside vendors for biodiesel | 32 |

### 3.2 Potential of Biodiesel from vegetable waste resources

In this study, questionnaires were administered to road side vendors and some households in Ghana. Also, secondary data on waste vegetable oil resources from hotels and restaurants around the country was used as time was a challenge and much work has been done to determine the WVO from restaurants. Excel and SPSS were used to evaluate the data collected.

**Step 1**

Waste Vegetable Oil from households

Questionnaires for this survey was made using Google forms, the link to the form was sent on social media platforms to Ghanaians to be filled, this was to determine the WVO they use in their households. A copy of the questionnaire is in (Appendix A).

**Step 2**

Waste Vegetable Oil from roadside vendors

This was carried out using structured questionnaires (Appendix B) in a cross- sectional study to elicit information from food vendors along roadsides in some parts of Accra; Asylum down, Osu, Amasaman, Labadi, Danquah Circle..

Table 3.2: Respondents from wayside vendors

| Foods sold | Frying foods | Number of sellers interviewed |
|---|---|---|
| **Waakye** | Fish, meat | 5 |
| **Beans(gob3)** | Plantain | 6 |
| **Jollof, Plain Rice &Stew** | Meat, fish, chicken | 5 |
| **Fried rice & chicken** | Chicken | 2 |
| **Kenkey & fish** | Fish, shrimps | 3 |
| **Koko & Koose, Pinkaso, Befloaf** | Befloaf, Koose, Pinkaso | 4 |
| **Fried yam** | Yam, sausage, gizzard, chicken, fish | 5 |
| **Kelewele (fried spiced plantain)** | Kelewele | 2 |

**Step 3**

Waste Vegetable Oil from Restaurants

Data of WVO from restaurants from 5 main regions; Sunyani, Accra, Kumasi, Takoradi and Tamale of Ghana was acquired. According to literature, as at the time of research there were 780 hotels across the country of which 340 hotels was sampled randomly. 215 hotels were sampled in Accra, 16 in Sunyani, 14 in Takoradi, 15 in Tamale and 80 in Kumasi [96].

## 3.3 Potential of Biodiesel from Marginal lands

For the purposes of this study, four steps were implemented. In the first step, marginal land resources suitable for bioenergy in Ghana is identified. Secondly, energy crops that have been proven to be biofuel sources as per literature were chosen, in the third step, the environmental requirements of the energy crops were reviewed. This included soil, climate, and topography needs. In the final stage, a multi factor assessment was used to evaluate the potential of bioenergy in Ghana based on the marginal land availability as well as the conditions suitable for the chosen energy crops.

**Step 1**

3.3.1 Identification of marginal land

In this study, marginal lands are referred lands which are not suitable for profitable agricultural purposes.

Marginal land which was suitable for cultivating the energy plants was identified.

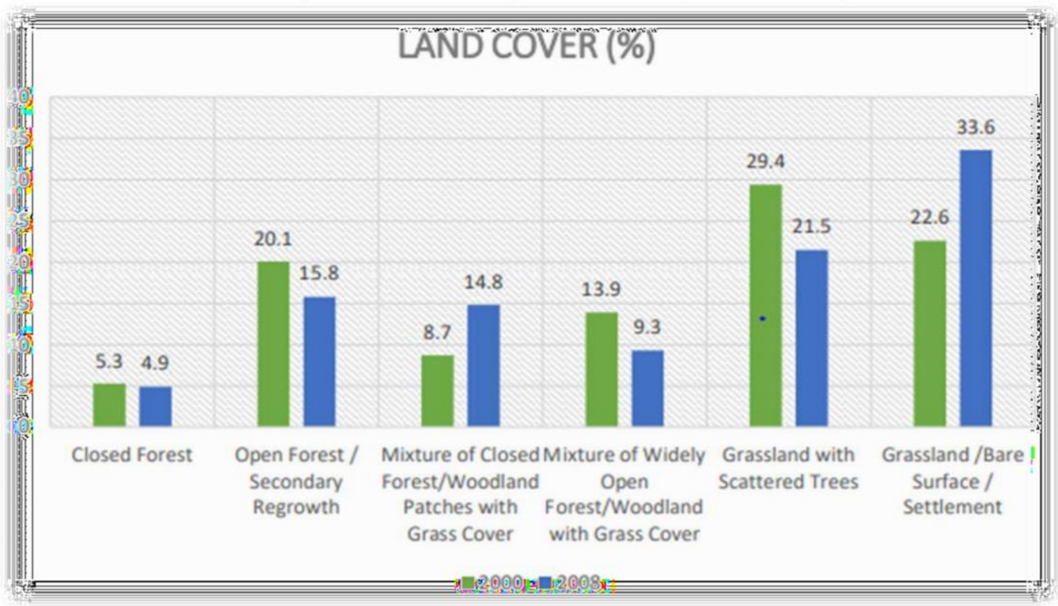



Figure 3.3: Area Statistics for the land cover/Use Classes (2000 & 2008)

Source: [99]

Fig 3.3 is a graph showing the Land use classes over the years. It is realized that, bare surface/ settlement has increased greatly over the years. This possess a threat to the availability of lands not suitable for agriculture.

**Step 2**

3.3.2 Identification of Energy plants

Energy plants suitable for bio-fuel development were identified. Based on their biological characteristics, ecological requirements, etc. the suitable place for its cultivation was determined from literature. Out of the several bioenergy crops identified, 3 were chosen using Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to an Ideal

Situation (TOPSIS). This selection was based on yield/ acre, food security, favorable conditions, job creation, land requirements etc.

**Jatropha**

It is a hardy shrub that can grow in semi-arid regions and on soils of poor quality. Jatropha is easy to establish and grows relatively fast. It has low soil nutrient requirements. It can help reclaim marginal lands, it as well serves as a protective hedge and since it is not good for human consumption provides a solution to the food versus fuel argument. [98].

Table 3.3: Bioenergy plant characteristics and their ability to grow on marginal lands

| **Bioenergy Crop** | **Characteristics** | **Ability to grow on Marginal lands** |
|---|---|---|
| Cassava | Drought and low soil fertility tolerance [97] | Can grow very well [97] |
| Jatropha | It is a multi-purpose plant. It can restore marginal lands [98] | Can grow very well |
| Palm fruit | Grows either spontaneously or when cultivated [99] Establishes fairly well on relatively poor soils [100] | Can grow on marginal lands |
| Sunflower | Performs relatively well even in drought. It is not prone to major diseases and pests [101]. | Can survive on all land types but waterlogged [102] |
| Neem | Can grow on arid and semi-arid lands [35] | Can grow on marginal lands [35] |
| Sugarcane bagasse | It is a lignocellullosic which is a byproduct of sugarcane after sugar extraction. | It is a byproduct of a crop that can survive on marginal lands |

**Azadirachta indica (Neem)**

This crop is a non-edible plant that can be used as biodiesel feedstock. Neem can grow in almost all soil kinds; clay, saline, alkaline, dry, stony, shallow soils and even on solid having high calcareous soil. It does very well in arid and semi-arid temperate regions with maximum shade temperature as high as 49 1C and the rainfall is as low as 250 mm [35]

**Sunflower oil**

Sunflower has the ability to grow in a variety of soil conditions but does well in soils that are well drained and with high water-holding capacity. It is considered drought tolerant. Sunflower can adapt to a variety of conditions [103].

**Cassava**

This is a shrubby perennial crop that grows typically in tropical regions. It has a tolerance for drought and low soil fertility [104].

**Sugarcane Bagasse**

Bagasse, is a biomass feedstock, and a potential biofuel (ethanol). It is a byproduct of sugarcane and is generated at the industrial units, and as such free of transportation costs. This is promising because from each 10 million tons of dry biomass, 600 million gallons of ethanol could be produced, considering the use of its cellulosic part only [33].

AHP

In this research, this method (AHP) is used to determine weights for TOPSIS.

**Chosen Criteria**

1) Social 2) Environmental 3) Economic

**Sub Criteria**

**1) Social**

Job Creation

Social Acceptance

**2) Environmental**

Land Requirements

Growing Conditions

**3) Economic**

Land Cost

Food Security

First, values are assigned on a scale of 1-9, 1-being equal importance, 3- Moderate Importance, 5-Strong Importance, 7- Very Strong Importance, 9-Extreme Importance, 2, 4,6& 8 are for compromises between the former; 1,3,5,7& 9.

Do a pairwise comparison

CI=$\frac{\lambda \max - n}{n-1}$

Where CI is consistency index and CI < 0.1 to be consistent.

Eigen Vectors , which is calculated for using a matrix of the criteria or subcriteria you are determining weights of

W= Weight

W=$\frac{EV1}{T}$%, T is sum of eigen vectors

TOPSIS

In this method two artificial alternatives are hypothesized; a. Ideal alternative, the one which has the best level for all attributes considered and b. Negative ideal alternative, the one which has the worst attribute values. TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative.

In TOPSIS, we assume that we have **m** alternatives (options) and **n** attributes (criteria) and we have the score of each option with respect to each criterion.

- Let $\mathbf{x_{ij}}$ score of option **i** with respect to criterion **j**

We have a matrix an $\mathbf{m \times n}$ matrix, $\mathbf{X = (x_{ij})}$ .

- Let **J** be the set of benefit attributes or criteria (more is better)
- Let **J'** be the set of negative attributes or criteria (less is better)

1. Construct a normalized decision matrix. In this step, various attributes are transformed into non-dimensional attributes to allow for comparisons across criteria. $\mathbf{r_{ij} = x_{ij} / \sqrt{(\Sigma x^2_{ij})}}$ **for i=1,…,m; j=1…,n**

2. Construct the weighted normalized decision matrix.
   - ✓ Assume we have a set of weights for each criteria $\mathbf{w_j}$ for **j = 1,…n.**
   - ✓ Multiply each column of the normalized decision matrix by its associated weight.
     - ✓ An element of the new matrix is: $\mathbf{v_{ij} = w_j r_{ij}}$

3. Step 3: Determine the ideal and negative ideal solutions.
   - ✓ Ideal solution: $\mathbf{A^* = \{ v_1^*, \ldots, v_n^* \}}$, where $\mathbf{v_j^* = \{ \max (v_{ij}) \text{ if } j \in J ; \min (v_{ij}) \text{ if } j \in J' \}}$
   - ✓ Negative ideal solution: $\mathbf{A' = \{ v_1', \ldots, v_n' \}}$, where $\mathbf{v' = \{ \min (v_{ij}) \text{ if } j \in J ; \max (v_{ij}) \text{ if } j \in J' \}}$

4. Calculate the separation measures for each alternative.
   - ✓ The separation from the ideal alternative is: $\mathbf{S_i^* = [ \Sigma (v_j^* - v_{ij})^2 ]^{1/2}}$ $\mathbf{i = 1, \ldots, m}$
     - ✓ Similarly, the separation from the negative ideal alternative is:

$$\mathbf{S'_i = [ \Sigma (v_j' - v_{ij})^2 ]^{1/2} \quad i = 1, \ldots, m}$$

5. Calculate the relative closeness to the ideal solution $\mathbf{C_i^*}$

$$\mathbf{C_i^* = S'_i / (S_i^* + S'_i), \qquad 0 \le C_i^* \le 1}$$

Select the option with $\mathbf{C_i^*}$ closest to 1.

The equations for the AHP and TOPSIS was put in excel to aid in the selection, results of the in the Appendix, Appendix F to Appendix N.

**Step 3**

3.3.4 Evaluation on the bioenergy potential of energy plants

A suitability analysis, using ArcGIS, was used to evaluate the potential of bioenergy in Ghana based on the marginal land availability as well as the conditions suitable for the chosen energy crops (sugarcane, neem, jatropha).

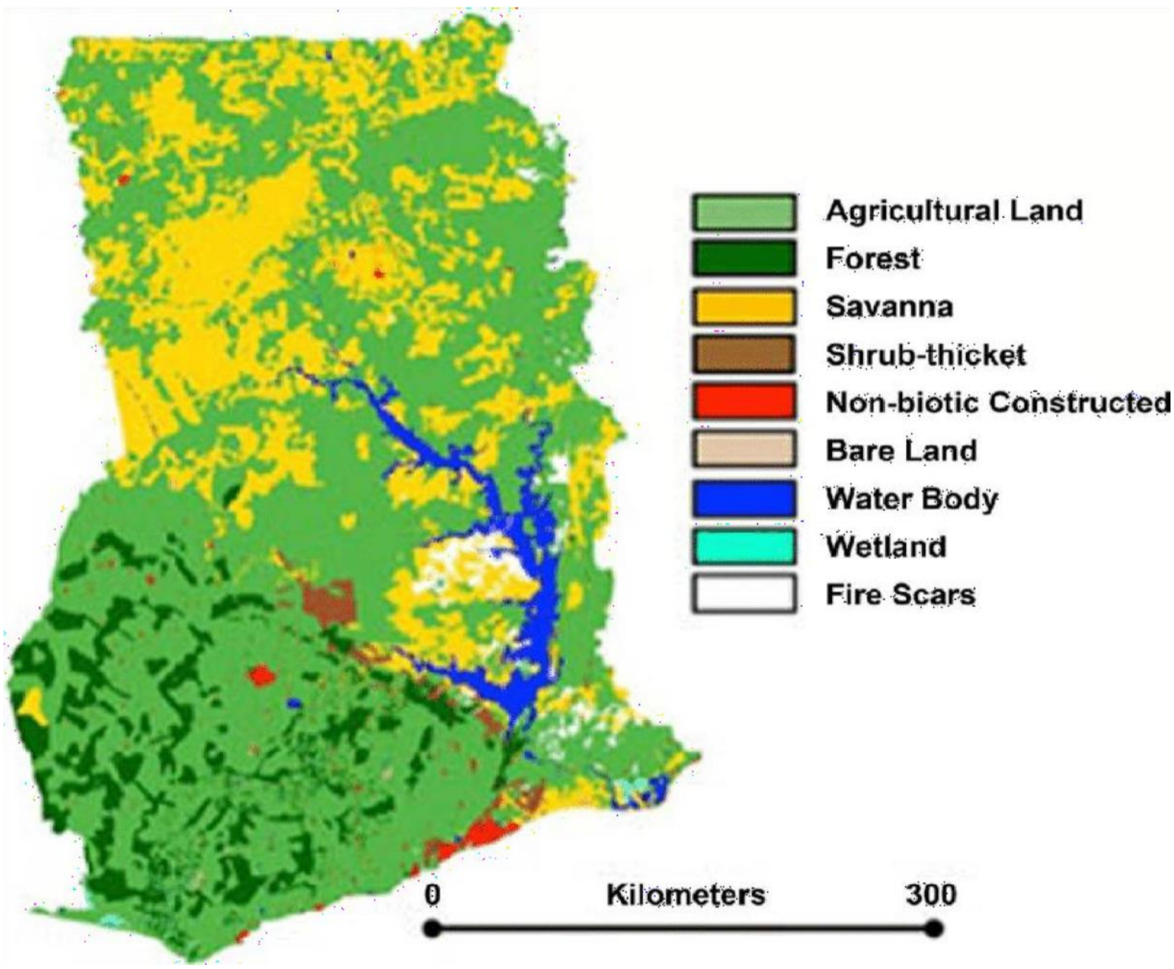



Figure 3.4: Land use map

Source: [105]

**Step 4**

3.3.5 Calculating the GHG emissions

Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrogen dioxide ($N_2O$), Hydroflourocarbons (HFC), Perflourocarbons (PFC), Sulphur hexafluoride (SF6)

The 3 most important GHG in the atmosphere however, are $CO_2$, $CH_4$ & $N_2O$. CO2 is the GHG we hear about most of the time.

3.3.5.1 Calculating the GHG emissions

To calculate for GHG emissions, there is a need for Emission factor, Global Warming Potential.

- **Emission factor** is a measure of the average amount of a specific pollutant into the atmosphere by a specific source. It is expressed in kilograms of the particulate per ton (or metric ton) of the fuel [105].
- **Global Warming Potential** (**GWP)** is a measure of how much energy one ton of an atmospheric gas will absorb over a specific period relative to one ton of $CO_2$ [106].

Global Warming Potentials of $CO_2$, $CH_4$ & $N_2O$ are 1, 25 and 298 respectively.

Calculations were made in excel to determine how much GHG emissions can be reduced.

Table 3.4: GHG emission calculation formulas

| | |
|---|---|
| GHG Emissions (kg) = | Fuel (litre) * Emission factor (kg/litre) |
| GHG Emissions (tonnes) = | GHG Emissions (kg) / 1000 |
| Global Warming Potential (tCOe) = | GHG Emissions (tonnes) * GWP |

Table 3.5: Land resource characteristics, restricting the cultivation of agricultural crops but effectively sustaining bioenergy plants (soil, rainfall, climate, topography, vegetation, etc.)

| **Bioenergy Plant** | **Soil** | **Rainfall** | **Climate** | **Topography** | **Vegetation** |
|---|---|---|---|---|---|
| Cassava | Well drained soil, not extremely stony, not too shallow at least 30cm [107] | 50mm rainfall per month<br>1000mm annual preferred [107] | Warm Humid Climate [108]<br>25 ºC -29 ºC stops growing below 10ºC [97] | Low lands mainly about 80% of cassava cultivated in Africa on lowlands [97] flat terrain [107] | Tropical lands [108] |
| Jatropha | Adapted to dry soils. However does well even in infertile and even in poor stony soil [109] | 254mm annual rainfall [109] | Favorable temperature ranges 20ºC- 40 ºC can however endure temperatures lower than 10 ºC and higher than 50 ºC for a short period [109] | lowlands [110] | Tropical lands but can thrive in Semi-arid regions [98] [111] |
| Palm oil | Deep soil [112] Can be grown on a large range of soils. Requires easily penetrable soils with good moisture retention [100] | 2000-2500mm annual rainfall [113]<br>Dry periods must not exceed 2-3 months [100] | Relatively high temperature [112] Thrives in temperature ranging 24 ºC-28 ºC. The lowest mean temperature that supports its growth is 20 ºC [113] Below 20 ºC growth is likely to stop [100] | Low lands [100] | Rainy Tropical lowlands [112] |

| | | | | | |
|---|---|---|---|---|---|
| Sunflower | It can grow in a wide range of soils, from sandy loam to clay soils. Soils with good water holding capacity is preferred though [101] Grows very well in moist-rich soils, poor growth in gravel and saline soils [114] should be planted 1 – 2 inches deep [115] | Require 500mm-1000mm of rainfall [101] | The optimum temperature for sunflower growth is 23 $^{o}$C-28 $^{o}$C, a higher temperature range say, 34 $^{o}$C does not really affect productivity. Extremely high temperatures however reduce oil content [101]. | Variable but does not tolerate shade [114] | |
| Neem | Can cope with infertile, rocky and dry soils, grows well on deep sandy soils. Clay not suitable. Can cope | Drought tolerant. Can survive 152mm but optimum is4571193mm annual | Optimum temperature range of 10 $^{o}$C -37 $^{o}$C. Can however endure not more than 50 $^{o}$C and not less than 5 $_{o}$C | | Dry and hot habitats [116] |

| | | | | | |
|---|---|---|---|---|---|
| | salty soil with pH level between 5-8. Best pH however is 6.2-7 | | | | |
| | | rainfall | | | |

| Energy Crop | Temperature | Precipitation | Soil moisture tolerance | Soil moisture holding capacity (mm per meter soil depth) |
|---|---|---|---|---|
| **Jatropha** | 20ºC- 40 ºC | 254mm annual rainfall | Intolerant of water logged conditions [117](sandy) | 20-40mm |
| **Sugarcane** | 20 ºC -27 ºC | 1000-1500mm annual | Does well in well drained soils (sandy) | 20-40mm |
| **Sunflower** | 23 ºC-28 ºC | 500mm-1000mm of rainfall | Moist soils optimum(sandy loamy) | 35-110mm |
| **Neem** | 10 ºC -37 ºC | 457-1193mm annual | Does well in well drained soils(sandy soils) | 20-40mm |

## CHAPTER 4

## 4. RESULTS AND DISCUSSION

This section shows the results from our survey which was to determine the potential of waste vegetable oil as biodiesel feedstock from households and roadside vendors and the spatial images from ArcGIS, the outcome of our marginal land potential determination.

### 4.1 Potential of Waste Vegetable Oil for biodiesel from households

In this section, the results from our survey to determine potential of WVO households is shown and discussed.

In the survey, the respondents were asked the oil type they use for frying. It was revealed as in (fig 4.1) that, 64% of the respondents use vegetable oil for frying, 1.95% fry with Sunflower and palm oil and 31% use both vegetable oil and palm oil for frying.

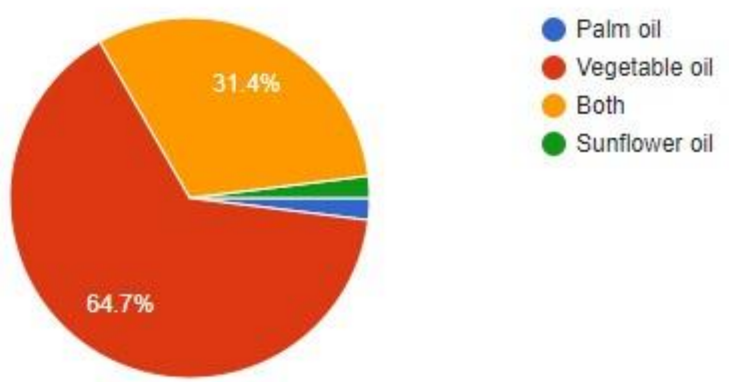



Figure 4.1: Oils used for frying

Source: Author's field survey

In order to know how available WVO will be if used as feedstock for biodiesel. The respondents therefore had to tell how often they fry. As shown in the chart below Fig 4.2, 27% of the people interviewed fry always, 17.6% fry weekly, 15.7% and a higher fraction, thus 39.2% fry irregularly.

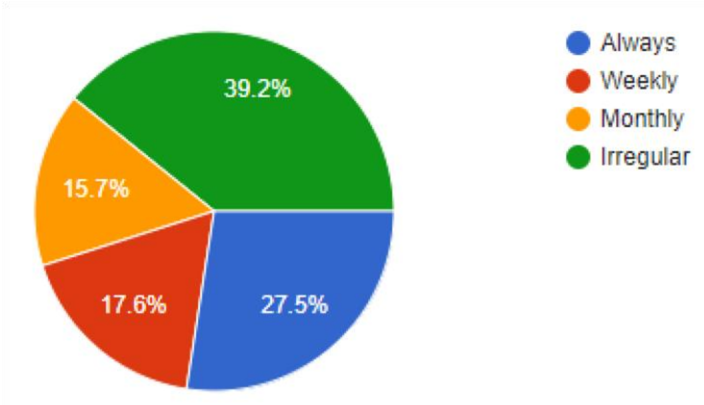



Figure 4.2: A chart showing how often people fry

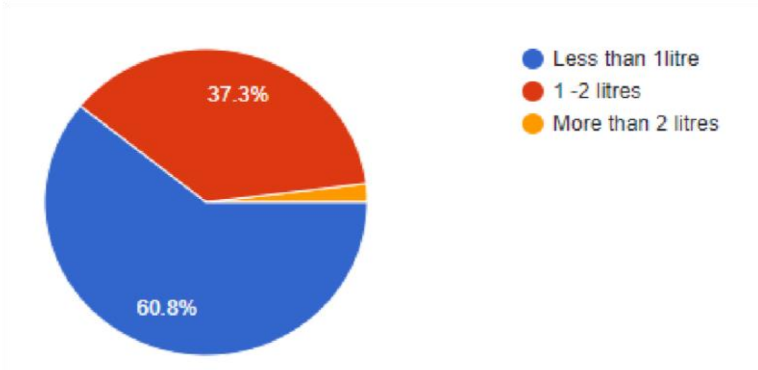
Source: Author field work

Also, the quantity of oil used in frying was asked. Most people interviewed fry with less than 1 litre of vegetable oil a month. As in the chart (Fig 4.4) generated, 60.8% of the interviewee's use less than 1 litre every month, 37.3% use between 1- 2 litres and 1.9% use more than 2 litres. With palm oil use, 80.4% of the respondents use less than 1 litre, 3% use more than 2 litres and 17.6% use between 1-2 litres (Fig 4.3).

month (palm oil)

Source: Author's field survey

So as to know how available WVO will be, the survey enquired from our interviewees how many times they reuse their WVO. According to the survey, 51% of the interviewees reuse their waste



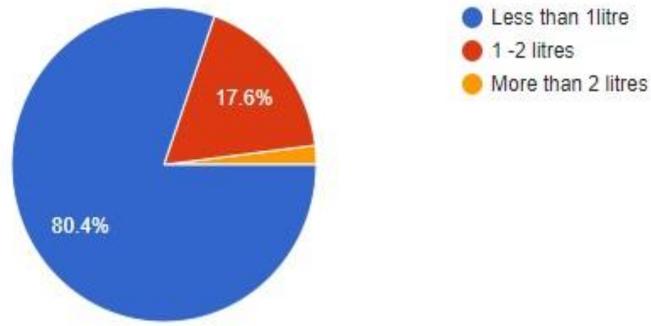




Figure 4.3: Litres of Oil used per month (Vegetable oil) Figure 4.4: Litres of Oil used per vegetable oil. 37% sometimes use reuse and 11.8% just wash it into drains when washing the frying pans (fig 4.4).

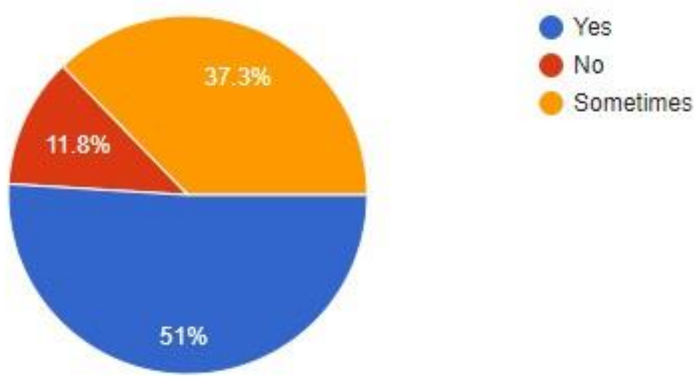



Figure 4.5: Use of waste vegetable oil

Source: Author's field survey

A greater percentage reuse the oil about 2-3 times before discarding if it does not finish. 42.9% reuse several times based on the quantity and the color changes. Depending on what was fried the oil will be used till it is dark and can't be used any more (fig 4.5).

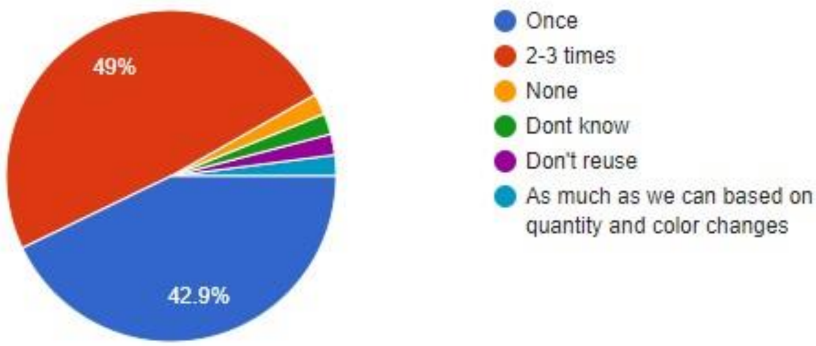



Figure 4.6: Number of times of reuse

Source: Author's field survey

To know how much WVO is generated monthly, the interviewees were asked the quantity of waste vegetable oil generated monthly. 63.3% of our respondents cannot really tell the quantity of oil they discard monthly as the\y do not take note. It is most of the time spilled into drains when washing the frying pans if it cannot be reused. 6.7% discard about 500ml and 30% less than 500ml (Fig 4.6)

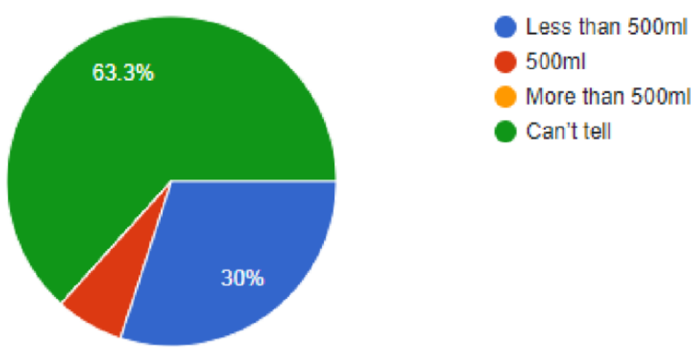



Figure 4.7: Chart showing quantity of oil discarded monthly

Source: Author's field survey

That means, the quantity of WVO from households will be:

Respondents: 101

1. Assuming the number of respondents who don't remember how much they discard, discard 100ml

2. Assuming those who discard less than 500ml, discard 350ml

Thus,

63.3%*101 = 64 households 64 * 100ml = **6400ml**

30%*101 = 30households 30*350ml = **10500ml**

6.7%*101= 7 households

7*500ml = **3500ml**

Total WVO generated from households in Accra= (6400+10500+3500) ml

=**20400ml**

Therefore, from the survey, we can get at least **20.4 litres of WVO** from 101 households in Accra monthly.

To know if people will be ready to give out their WVO to be used as biodiesel feedstock, we enquired from our respondents, the outcome is shown in fig 4.8. 80% were in the affirmative, thus, are ready to give out their WVO as biodiesel feedstock. 15.7% said it depends on if they will profit from it or not. 2% are not sure as it will depend on what they will get from giving it out since they will have to buy for other frying should they give it out.

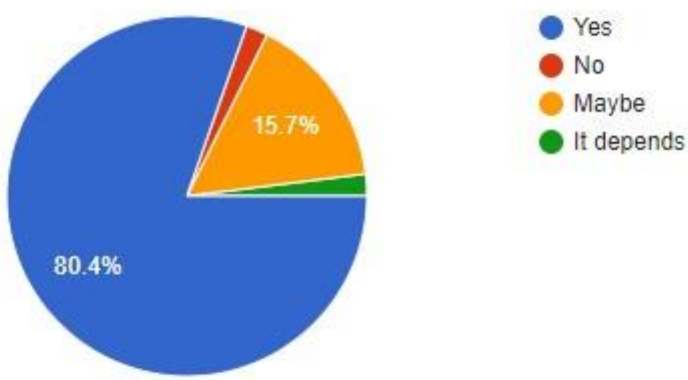



Figure 4.8: Chart showing people who will want to give out their WVO for biodiesel feedstock

Source: Author’s field survey

From fig 4.9, 57.4% are ready to give out their waste vegetable oils for free, 34% will give it at a cost. This makes biodiesel from WVO more interesting as this will even reduce capital cost and it is possible more people will be willing to offer as they are sensitized about biodiesel.

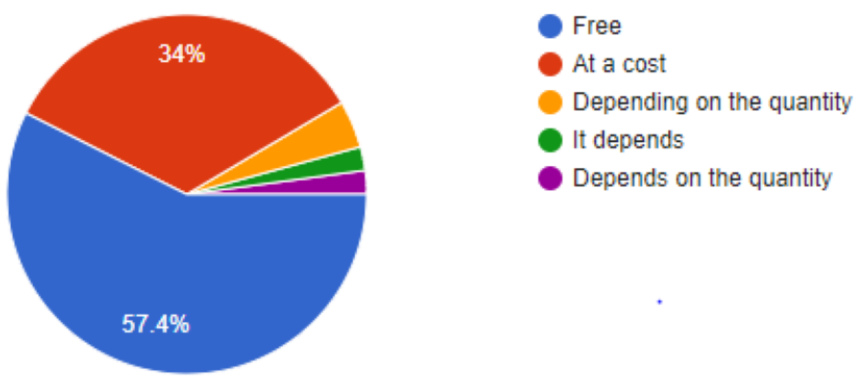
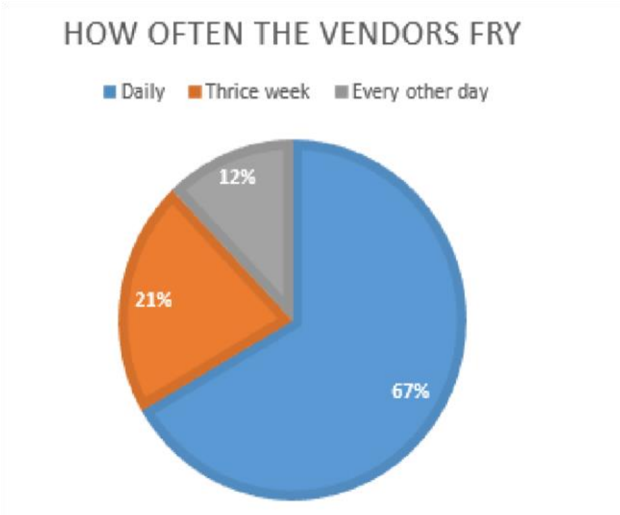



Figure 4.9: Chart showing percentage of people who will sell their WVO at a cost or give it out for free.

Source: Author's field survey

**4.2 Potential of Waste Vegetable Oil for biodiesel from wayside vendors**

Wayside vending happens to be a common business here in sub-Saharan Africa. Foods are sold on the streets from dawn to dusk in very busy cities and areas like Osu in Accra. Foods such as fried yam with shito, fish, chicken, sausage or gizzard are sold mostly during the day. Kelewele (fried spiced ripe plantain) is mostly sold late afternoon till evening, fried plantain which is an accompaniment for beans gob3 which is sold from morning till evening and even waakye (beans and rice) in some cases. Waakye sellers mostly fry fish and meat as well and it is sold about the same period as gob3 (gari and beans). Koose, Pinkaso, befloaf, are all foods fried, which are taken in the mornings or evenings with koko (porridge).



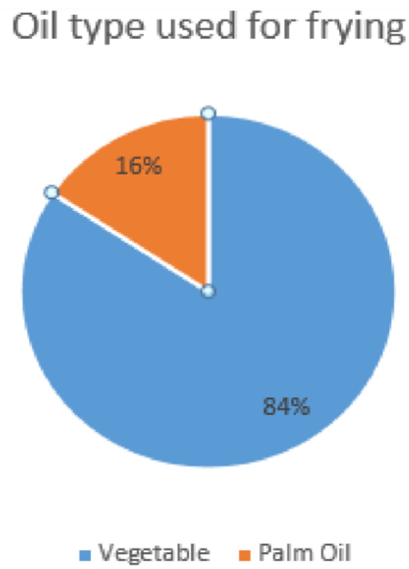



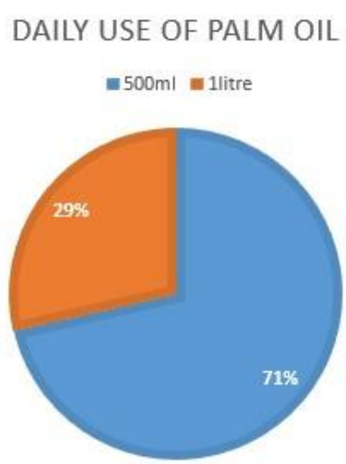

Figure 4.10: How often the vendors fry

Source: Author's field survey

Figure 4.11: Oil type used for frying

Source: Author's field survey

Figures 4.10 and 4.11 reveal how often the respondents of the wayside survey fry and the oil they use respectively. It was revealed that 67% fry daily and 84% use vegetable oil in frying.



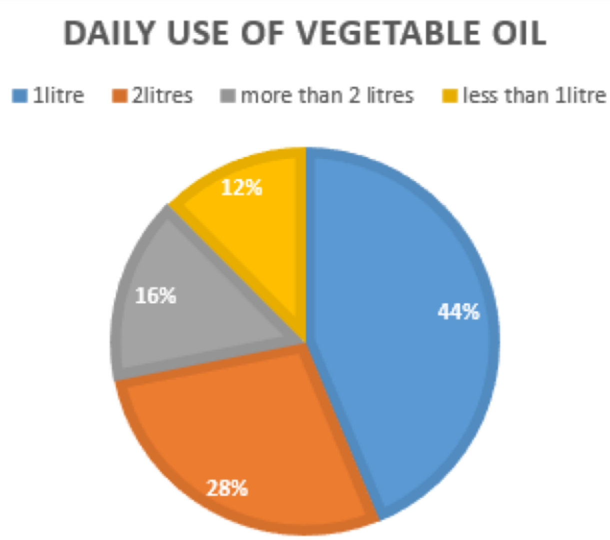




Figure 4.12: Daily use of palm oil

Source: Author's field survey

Figure 4.13: Daily use of vegetable oil

Source: Author's field survey

The survey showed that, 71% of our respondents use about 500ml of palm oil daily to fry (fig 4.12). 44% use about 1 litre of vegetable oil daily and 28 & use 2 litres (fig 4.13).

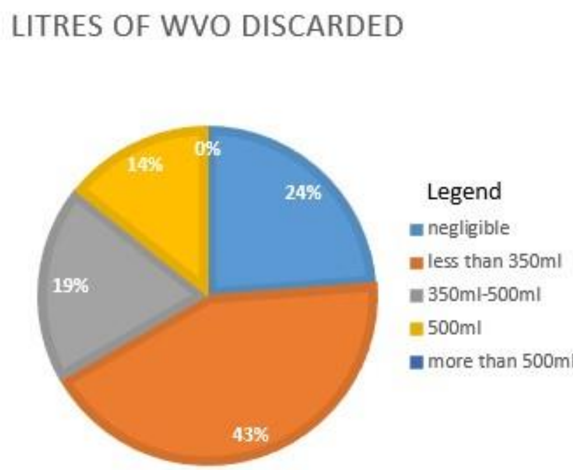



Figure 4.14: Litres of WVO discarded daily

Source: Author's field survey

24% of our interviewee's said they discard very little or negligible quantity of WVO daily, 43% discard about 350ml (Fig 4.14)

Thus, the quantity of WVO from wayside vendors will be:

Respondents: 32

**Assumptions**

1. Assume the number of respondents who discard negligible amount of WVO, discard 50ml
2. Assume those who discard less than 350ml, discard 250ml
3. Assume those who discard between 350ml – 500ml discard 400ml
4. Assume those who discard more than 500ml discard 600ml

Thus, 24%*32 =7 of the 32 vendors discard;

7*50ml = **350ml**

43%*32 = 14 vendors throw away,

14*250ml = **3500ml**

19%*32 = 6 vendors

6*400ml = **2400ml**

14%*32 = 5

5*500 = **2500ml**

Total WVO generated from households in Accra = (350+3500+2400+2500) ml

= **8750ml**

Therefore, from the survey, we can get at least **8.75 litres of WVO** from **32 wayside vendors** in Accra **daily**.

Thus assuming **20 working days** in a month, we get **20days*8.75litres** = **175litres a month**

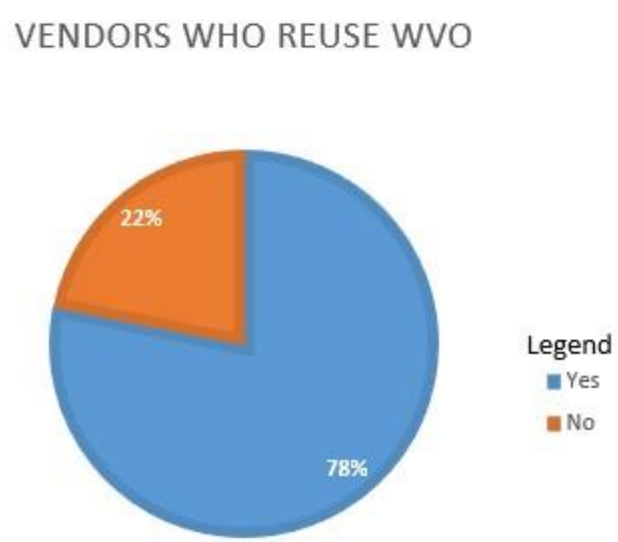



Figure 4.15: Vendors who reuse

Source: Author’s field survey

A good number, 78% of the vendors interviewed reuse their WVO (fig 4.15).

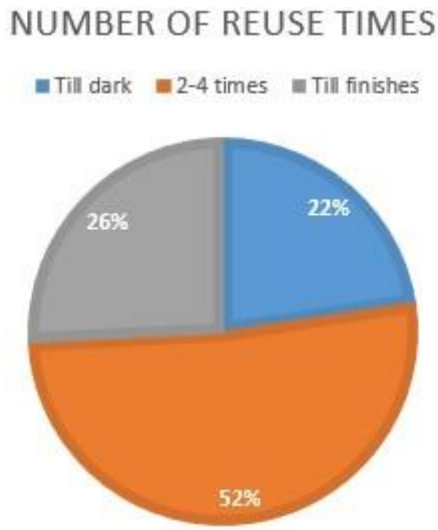



Figure 4.16: Number of times of reuse

Source: Author's field survey

The research revealed that, 52% reuse their WVO about 2-4 times before discarding if there is still some. 22% Reuse until the WVO is too dark to be reused again and the remaining 26% reuse until it finishes (Fig 4.16)

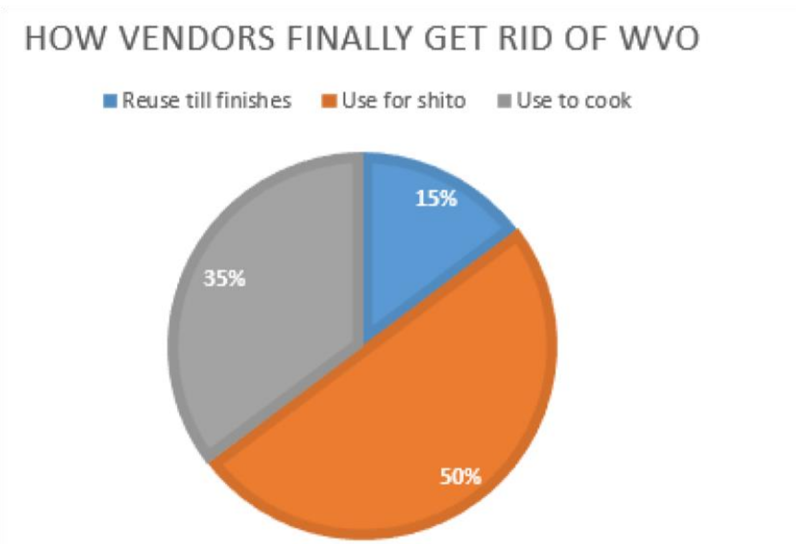



Figure 4.17: How vendors finally get rid of their WVO

Source: Author's field survey

Shito and stew, happens to be the final destination of WVO from the wayside, 50% use their WVO for shito, 35% use for cooking stews and 15% use till it finishes (fig 4.17).

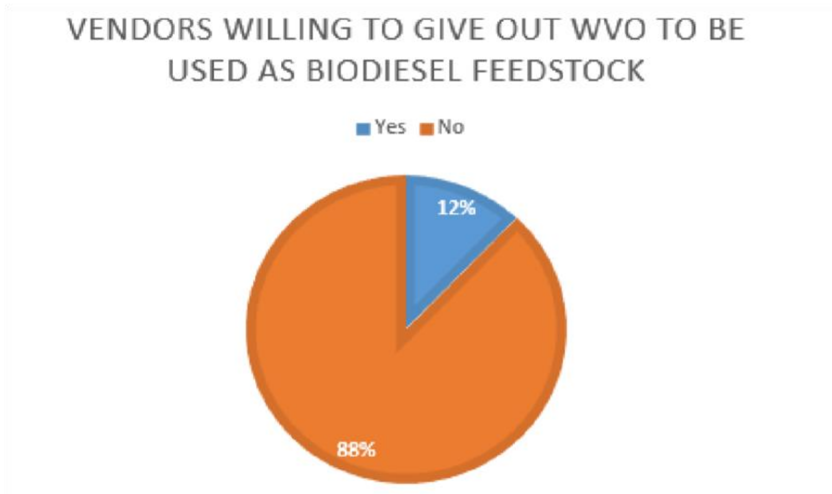



Figure 4.18: Vendors willing to give out WVO for biodiesel feedstock

Source: Author’s field survey

Only 12% of the way side vendors are willing to give out WVO for biodiesel feedstock. Most of the respondents argued that, the oil ( WVO) from frying is what they used for preparing shito or even stews so they are not going to give it out as it will cost more to reuse than to buy a new gallon of oil (fig 4.8)

### 4.3 Potential of Waste Vegetable Oil for biodiesel from hotels

Table 4.1: Amount of oil used and discarded as waste by the sampled hotels

| City | Avg. Quantity of Fresh Vegetable Oil Used Per Hotel monthly (litres) | Avg. Quantity discarded as waste Per Hotel monthly (litres) | % of oil discarded as waste |
|---|---|---|---|
| Accra | 162.6 | 54.5 | 34% |
| Kumasi | 64.8 | 12.6 | 20 |
| Sunyani | 220 | 48.3 | 22 |
| Tamale | 269.1 | 40.2 | 15% |
| Takoradi | 168.3 | 45 | 27% |

Source: [96]

Total average quantity of WVO from a hotel monthly**= (54.4+12.6+48.3+40.2+45) litres**

=**200.5 litres**

Assuming 200 hotels in Accra are ready to give out WVO monthly; We

have **200* 54.4litres = 27,200 litres** every month.

From 101 houses in Accra we have an average of **20.4litres** per month

**Total quantity of WVO from households, wayside vendors and hotels in Accra every month=**

**(20.4+175+200.5) litres**

**=395.9litres**

## 4.4 Potential of biofuel from marginal lands

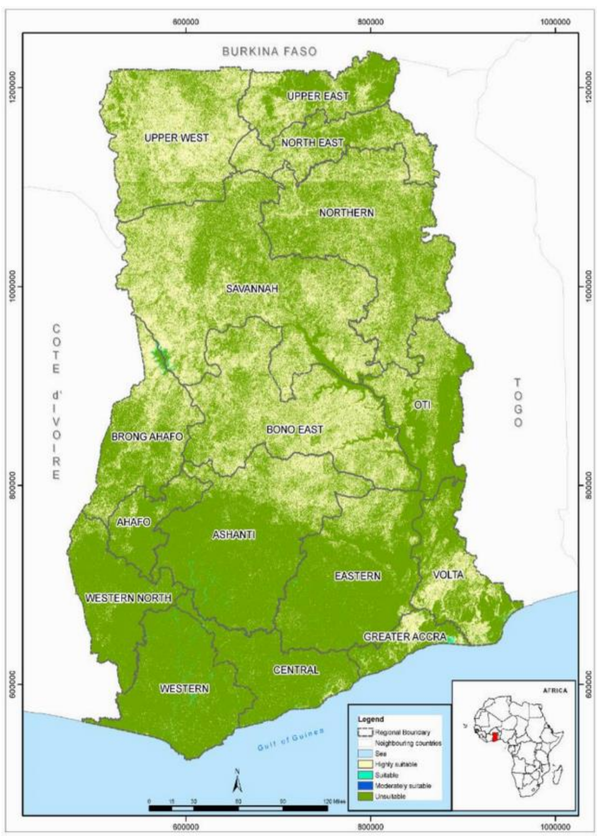



Figure 4.19: Map of Ghana Land Use Land Cover

Source: Author's field work (from ArcGIS)

In Fig 4.19, Land Cover Land Use (LULC) map which was classified into areas that are suitable for growing energy crops or not so from the legend, the green areas are very unsuitable and the yellow areas are highly suitable.

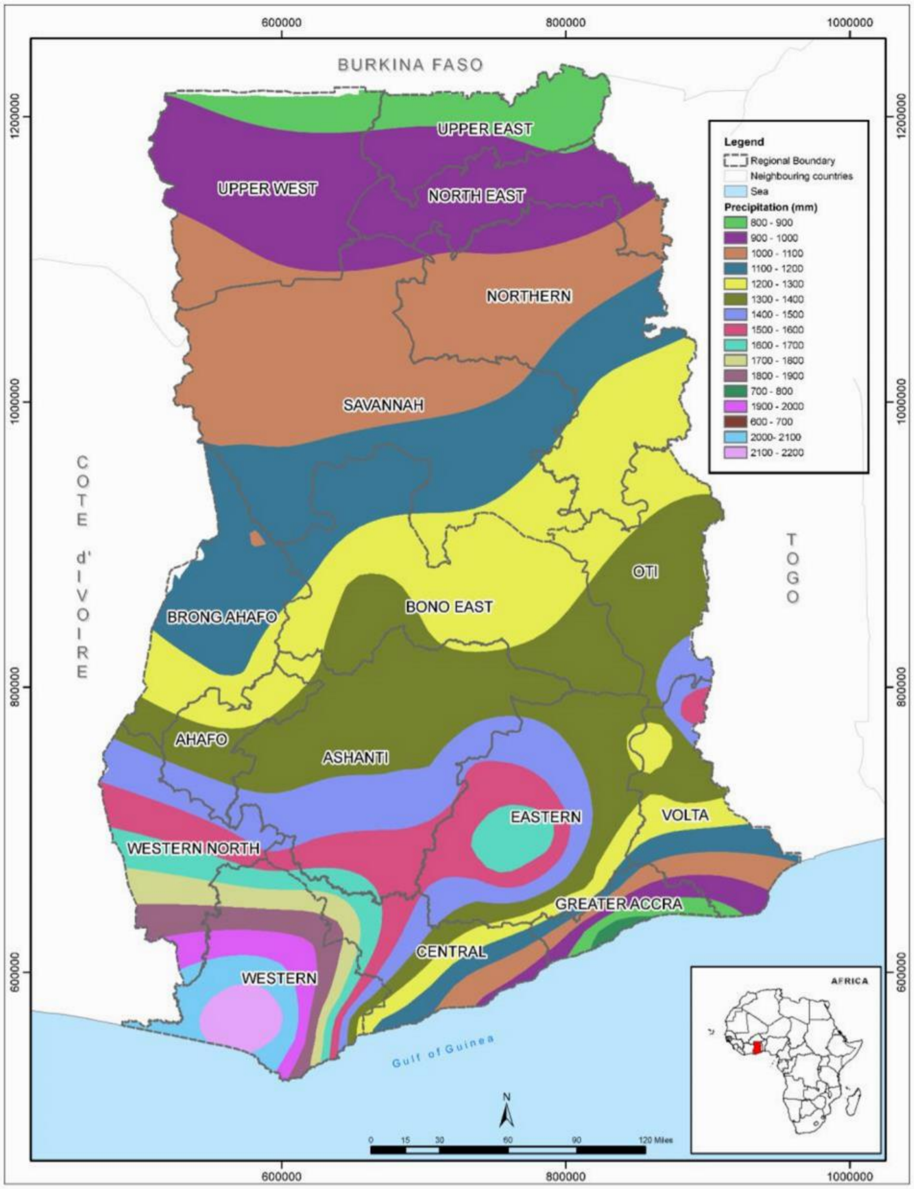



Figure 4.20: Precipitation Map of Ghana

Source: Author’s field work (from ArcGIS)

This map shows the precipitation range across the country.

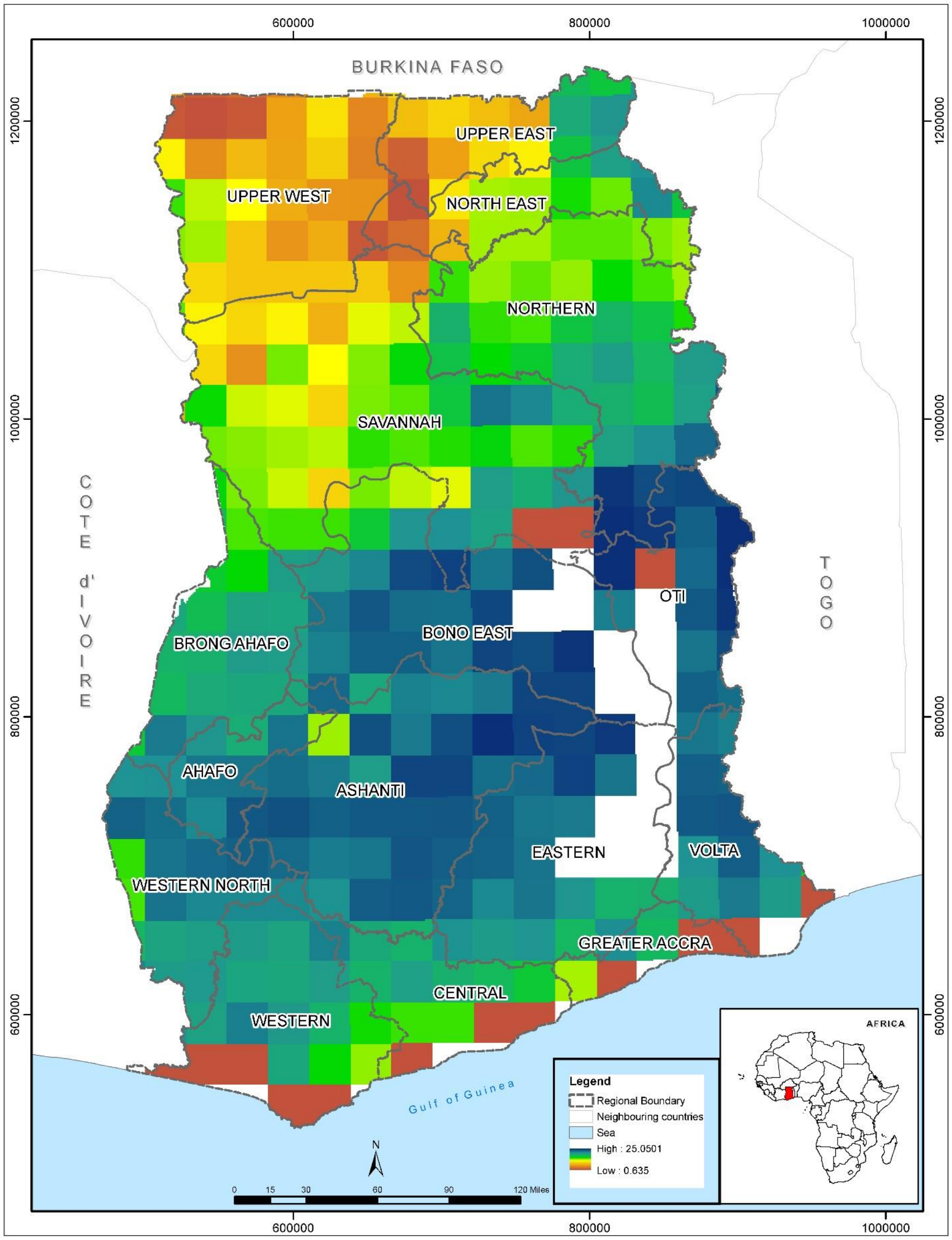



Figure 4.21: Soil Moisture

Source: Author's field work (from ArcGIS)

Fig. 4.2 is the soil moisture map. From the legend, the brown areas are low in soil moisture and the green to blue shade of colors are high in soil moisture. The energy crops selected require less soil moisture hence will perform better in the coastal and northern areas.

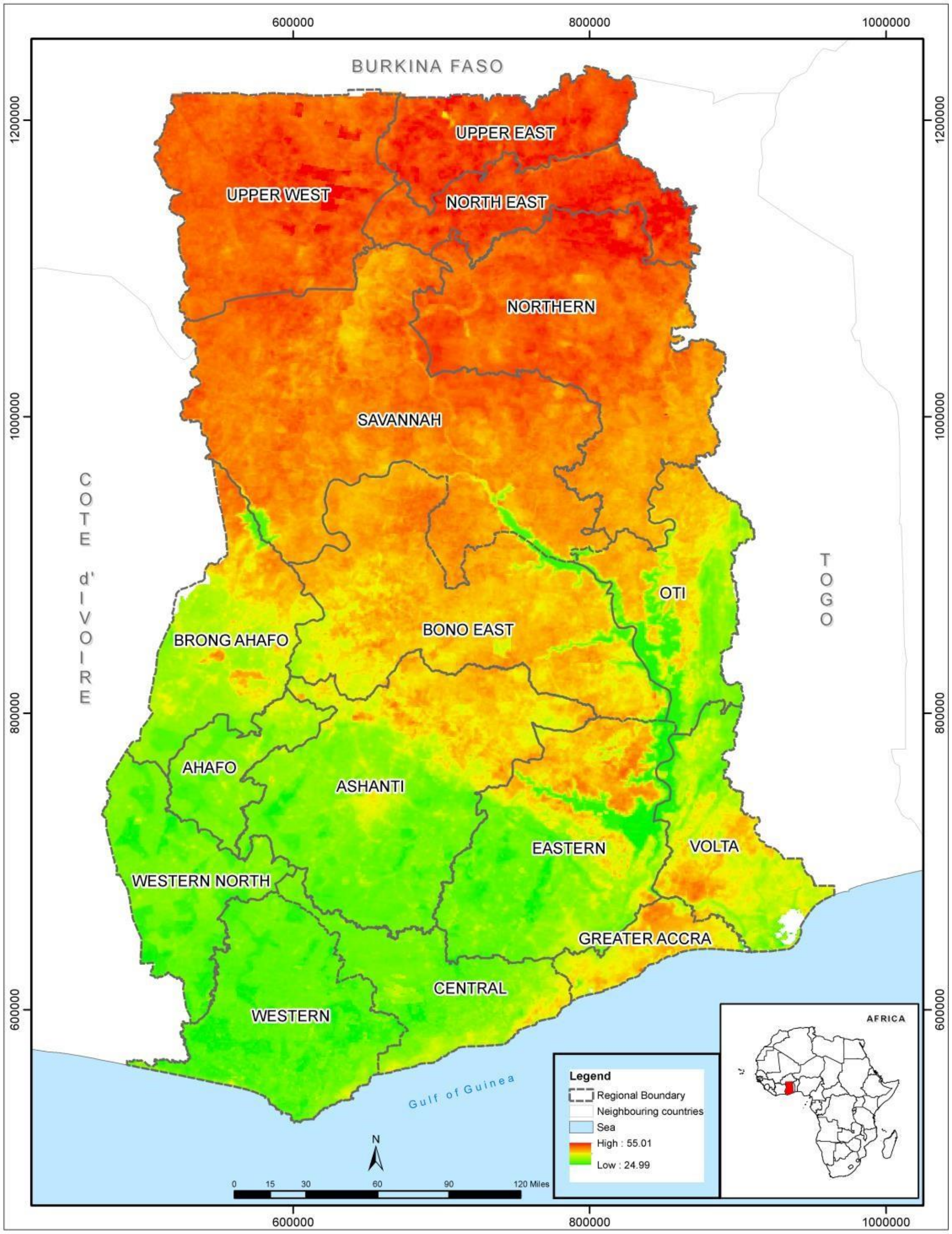



Figure 4.22: Map of Temperature

Source: Author's field work (from ArcGIS)

Some crops thrive better in temperate zones, others warmer climates. (Fig 4.22) is a map of temperature.

### 4.5 $CO_2$ emissions reduction

The calculations were made in excel using the equations mentioned in Chapter 3.

Table 4.2: Is a copy of a table from a calculator ade using excel

| | | GWP | Fuel (litre) | Emission factor (kg/litre) | GHG Emissions (kg) | GHG Emissions (tonnes) | Global Warming Potential (tCOe) |
|---|---|---|---|---|---|---|---|
| WVO | CO2 | 1 | 395.9 | 2.677 | 1059.8243 | 1.0598243 | 1.0598243 |
| | CH4 | 25 | 395.9 | 0.000108 | 0.0427572 | 4.27572E-05 | 0.00106893 |
| | N2O | 298 | 395.9 | 2.11337E-05 | 0.008366832 | 8.36683E-06 | 0.002493316 |
| | | | | | | | 1.063386546 |
| | | | | | | | |
| NEEM | CO2 | 1 | 13.7565 | 2.677 | 36.8261505 | 0.036826151 | 0.036826151 |
| | CH4 | 25 | 13.7565 | 0.000108 | 0.001485702 | 1.4857E-06 | 3.71426E-05 |
| | N2O | 298 | 13.7565 | 2.11337E-05 | 0.000290726 | 2.90726E-07 | 8.66363E-05 |
| | | | | | | | 0.036949929 |
| | | | | | | | |
| JATROPHA | CO2 | 1 | 355.829 | 2.677 | 952.554233 | 0.952554233 | 0.952554233 |
| | CH4 | 25 | 355.829 | 0.000108 | 0.038429532 | 3.84295E-05 | 0.000960738 |
| | N2O | 298 | 355.829 | 2.11337E-05 | 0.007519983 | 7.51998E-06 | 0.002240955 |
| | | | | | | | 0.955755926 |
| | | | | | | | |
| BAGASSE | CO2 | 1 | 462.96 | 2.677 | 1239.34392 | 1.23934392 | 1.23934392 |
| | CH4 | 25 | 462.96 | 0.000108 | 0.04999968 | 4.99997E-05 | 0.001249992 |
| | N2O | 298 | 462.96 | 2.11337E-05 | 0.009784058 | 9.78406E-06 | 0.002915649 |
| | | | | | | | 1.243509561 |

# CHAPTER 5

## 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

### 5.1 Summary

The study was conducted to determine the potential of biofuel from WVO and marginal lands in Ghana. For this study, some parts of Accra was chosen as case study for the determination of WVO potential from households and wayside vendors. These areas included; Osu, La, Asylum down and Amasaman. Questionnaires were administered to wayside vendors and households to find out about their WVO, what they do with it after use and if they are willing to give it out to be used as biodiesel feedstock.

The research had three main objectives. The first objective which was to assess the suitability of bioenergy crops production on marginal lands in Ghana was done by choosing several energy crops. AHP and TOPSIS was used to choose energy crops to considered for the study, taking into consideration, food security, land requirements, social acceptability, etc. this was done as some of the energy crops selected also served as food. In the end, Jatropha, Neem, Sunflower and Bagasse were chosen as biofuel feedstock for biodiesel and bioethanol. This then led to determination of the suitable conditions for cultivation of the chosen energy crops.

The second objective, was to estimate the potential of biofuels production from waste vegetable oil, marginal lands, and lignocellulosics. The first part of this objective was undertaken by administering questionnaires to wayside vendors and household within the selected areas in the capital. Also, secondary data about WVO from hotels in the country was acquired. From the survey, it was realized that we can get 20.4 litres of WVO from 101 households in Accra monthly and 175 litres a month from 32 wayside vendors. Based on secondary data obtained, an estimated amount of 200.5 litres of WVO can be obtained from a hotel in Accra every month.

The last but not least of the objective was to evaluate the GHG emissions reduction through production of biodiesel and bioethanol. This was to determine how much of GHG emissions we would be reducing by utilization from the biofuel potential based on the research. It was revealed that, WVO from the hotels, wayside vendors and households will reduce our emissions by 1.063386546 tCO2e

## 5.2 Conclusion

Based on the findings of this research, energy crops such as Jatropha, Neem, Sunflower and Sugarcane can grow on marginal lands. It was also revealed that, 395.9litres of WVO can be generated monthly as biodiesel feedstock. Thus we reduce GHG emissions by 1.063386546 $tCO_2e$. From one acre each, we reduce 0.036949929 $tCO_2e$, 0.955755926 $tCO_2e$ and 1.243509561 $tCO_2e$ of GHG emissions from Neem, Jatropha and Sugarcane bagasse respectively.

In conclusion, considering the potential of biofuel in Ghana, it will be expedient to consider introducing biodiesel into our energy sector especially as transport fuel in our quest to minimize GHG emissions and to augment the heavy reliance on fossil fuels.

## 5.3 Recommendation

Based on the findings of this research, I recommend that;

- The results of this research should be used as a basis for further research on cost and others factors that needs to be considered in the establishment of a biodiesel industry as we are sure of potential now.
- Existing policies on biofuel should be implemented
- Farmers should be encouraged to go into large scale cultivation of energy crops on marginal lands
- Government and for that matter, the responsible ministry and or institutions should put measures in place to ensure easy acquisition of lands for bioenergy crops cultivation
- The government and other institutions and stakeholders in the energy sector should invest in development of biofuels (biodiesel and bioethanol) for transportation
- Private investors should be encouraged to venture into the biofuel industry. Incentives and other attractive packages can be given to players in the biofuel sector
- There should be a sensitization of the citizenry about the health effects of re-using WVO for a long period so they give it out to be used as feedstock for biodiesel production
- Government can come to a consensus with wayside vendors, hotels, restaurants and other generators of WVO to provide or sell WVO to biodiesel producing companies
- The establishment of biofuel industries in Ghana should be promoted and this can be part of the one district one factory goal of the current government and create jobs

- The ministry and institutions in charge should put in place mechanisms for the collection or buying on WVO for biodiesel feedstock.
- Industries with bagasse as waste product can be liased with to get bagasse from thm to be used in ethanol production.

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# 7. Appendix

## Appendix A

**QUESTIONNAIRE**

**MASTER RESEARCH THESIS: by Angela Okuley**

**INSTITUTE: PAN AFRICAN UNIVERSITY INSTITUTE OF WATER AND ENERGY SCIENCES**

**TOPIC: ASSESSMENT OF BIOFUEL POTENTIAL ON MARGINAL LANDS AND FROM**

**VEGETABLE OIL WASTE RESOURCES IN A GHANA**

This questionnaire is to help determine the quantity of waste vegetable oil generated monthly from households.

Name of interviewee……………………………………………………………………………..

Location…………………………………………………………………………………………..

Frying foods.……………………………………………………………………………….......

Oil used (Vegetable/ Palm oil) ……………………………………………………………….

No. of Gallons used monthly (Vegetable oil)

………………………………………………………………………………….

No. of times is oil is used. (a) 1 (b) 2 (c) 3 (d) 4 (e) 5 or more. If not mentioned state……… No. of Gallons used monthly (Palm oil)

…………………………………………………………………………….

No. of times is oil is used. (a) 1 (b) 2 (c) 3 (d) 4 (e) 5 or more. If not mentioned state……… Do you discard the waste oil? (a) Yes (b) No

If yes, how? ........................................................................ and how many litres daily................

If no, what do you use it for? …………………….…………………………………………………..

Are you willing to sell waste vegetable oil? (a) Yes (b) No

At a cost or free? (a) At a cost (b) Free (c) It depends (d) Maybe

**Appendix B**

**QUESTIONNAIRE**

**MASTER RESEARCH THESIS: by Angela Okuley**

**INSTITUTE: PAN AFRICAN UNIVERSITY INSTITUTE OF WATER AND ENERGY SCIENCES**

**TOPIC: ASSESSMENT OF BIOFUEL POTENTIAL ON MARGINAL LANDS AND FROM VEGETABLE OIL WASTE RESOURCES IN A GHANA**

This questionnaire is to help determine the quantity of waste vegetable oil generated daily from wayside vendors.

Name of interviewee……………………………………………………………………………..

Location………………………………………………………………………………………..
Frying foods.…………………………………………………………………………….......

Oil used (Vegetable/ Palm oil) ………………………………………………………….

No. of Gallons used daily……………………………………………………………………….

No. of times is oil is used. (a) 1 (b) 2 (c) 3 (d) 4 (e) 5 or more. If not mentioned state……… Do you discard the waste oil? (a) Yes (b) No

If yes, how? ........................................................................... and how many litres daily................

Do you sell the waste oil? (a) Yes (b) No

If yes, at what price? ………………………………….............................

If no, what do you use it for? ……………………………………………………………………..

Are you willing to sell waste vegetable oil? (a) Yes (b) No

At what Price will you want to sell it? ..................................................................

**Appendix C**


Figure 7.1: Foods whose vendors were interviewed (A)

**Appendix D**


Figure 7.2: Foods whose vendors were interviewed B

**Appendix E**


Figure 7.3: Foods whose vendors were interviewed C

**Appendix F**

Table 7.1: AHP Criteria Weight Determination

| | | CRITERIA | | |
|---|---|---|---|---|
| | | Social | Economic | Environmental |
| | Social | 1 | 0.5 | 0.5 |
| | Economic | 2 | 1 | 0.3 |
| | Environment | 2 | 3 | 1 |

$\lambda 1 =$ 3.13538

$\lambda 2 =$ −0.0676899 +0.648756i

$\lambda 3 =$ −0.0676899 −0.648756i

n= 3

CI= $\frac{\lambda max - n}{n-1}$ CI < 0.1; Consistent

W=EV/T,

CI= 0.06769 ; consistent T= Sum of Eigen Vectors

EV=Eigen Vector

| | |
|---|---|
| W1= | 0.2 |
| W2= | 0.222222222 |
| W3= | 0.555555556 |

**Appendix G**

Table 7.2: AHP Sub-Criteria Weight Determination

SUB-CRITERIA

| SOCIAL | | |
|---|---|---|
| | Job Creation | Social Acceptance |
| Job Creation | 1 | 2 |
| Social Acceptance | 0.5 | 1 |
| | | |
| W1= | 0.666666667 | |
| W2= | 0.333333333 | |

| | ECONOMIC | |
|---|---|---|
| | Land Cost | Food Security |
| Land Cost | 1 | 0.5 |
| Food Security | 2 | 1 |
| | | |
| W1= | 0.333333333 | |
| W2= | 0.666666667 | |

| | ENVIRONMENTAL | |
|---|---|---|
| | Land Requirements | Growing Conditions |
| Land Requirements | 1 | 0.5 |
| Growing Conditions | 2 | 1 |
| | | |
| W1= | 0.333333333 | |
| W2= | 0.666666667 | |

**Appendix H**

Table 7.3: Weights of Criteria & Sub-Criteria determined using AHP

**Sub-**

**CriteriWeights**

**a (Pairwise Final Weight of Sub-**

**Weigh numbe comparison Criteria with respect t r Sub-Criteria ) to main**

**criteria**

**Social** 0.134 | 0.2 | SC1 | Job Creation | 0.67

0.066 | | SC2 | Social Acceptance | 0.33

**Economic** 0.1608 | 0.24 | SC3 | Land Cost | 0.33 | 0.0792

**Environmen** | | | | 0.67

**t** 0.1848 0.56 SC4 Food Security 0.33 0.3752

SC5 Land Requirements 0.67

SC6 Growing Conditions

**Appendix I**

Table 7.4: Criteria, Sub-Criteria, Units, Attributes & references

| **Criteria** | **Criteria** | **Subcriteria** | **Unit** | **Attributes** | **References** |
|---|---|---|---|---|---|
| **Social** | 1 | Job Creation | Number | More is better | Survey |
| | 2 | Social Acceptance | Number | More is better | Survey |
| **Economic** | 3 | Land Cost | $/kW | Less is better | n/a |
| | 4 | Food Security | tonnes | More is better | n/a |
| **Environment** | 5 | $CO_2$ Emissions | $tCO_2$ | Less is better | |
| | 6 | Land Requirements | acre | Less is better | [118] [119] [120] [121] [122] |

**Appendix J**

Table 7.5: Weights of Crops

| **Criteria** | **Sub-Criteria** | **Weight %** | **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
|---|---|---|---|---|---|---|---|---|
| | SC1 | 0.134 | 20 | 20 | 30 | 10 | 15 | 25 |
| **Social** | SC2 | 0.066 | 20 | 50 | 50 | 20 | 25 | 50 |
| | SC3 | 0.0792 | 2000 | 2000 | 2000 | 2000 | 2000 | 2000 |
| **Economic** | SC4 | 0.1608 | 10 | 95 | 90 | 15 | 30 | 80 |
| | SC5 | 0.1848 | 1 | 0 | 0.9 | 0.92 | 0.89 | 0.92 |

| **Environment** | SC6 | 0.3752 | 4 | 0 | 4 | 4 | 5 | 4 |
|---|---|---|---|---|---|---|---|---|

**Appendix H**

Table 7.6: an m*n matrix of our crops and weight $x^2_{ij}$

| | | **(Xij)^2** | | | |
|---|---|---|---|---|---|
| **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| 400 | 400 | 900 | 100 | 225 | 625 |
| 400 | 2500 | 2500 | 400 | 625 | 2500 |
| 4000000 | 4000000 | 4000000 | 4000000 | 4000000 | 4000000 |
| 100 | 9025 | 8100 | 225 | 900 | 6400 |
| 1 | 0 | 0.81 | 0.8464 | 0.7921 | 0.8464 |
| 16 | 0 | 16 | 16 | 25 | 16 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **(□$x^2_{ij}$)** | 4000917 | 4011925 | 4011516.8 | 4000742 | 4001775.8 | 4009542 |
| **√(□$x^2_{ij}$)** | **2000.23** | 2002.979 | 2002.8771 | 2000.185 | 2000.4439 | 2002.384 |

**Appendix I**

Table 7.7: Normalised matrix (rij) rij = xij / √ (□$x^2_{ij}$) for i=1,…, m; j=1…,n

| | | **rij** | | | |
|---|---|---|---|---|---|
| **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| 0.009999 | 0.0099851 | 0.014978 | 0.005 | 0.0074983 | 0.012485 |
| 0.009999 | 0.0249628 | 0.024964 | 0.009999 | 0.0124972 | 0.02497 |
| 0.999885 | 0.9985127 | 0.998563 | 0.999907 | 0.9997781 | 0.998809 |
| | | | | | |
| | | | | | |
| | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.004999 | 0.0474294 | 0.044935 | 0.007499 | 0.0149967 | 0.039952 | |
| | 0.0005 | 0 | 0.000449 | 0.00046 | 0.0004449 | 0.000459 |
| 0.002 | 0 | 0.001997 | 0.002 | 0.0024994 | 0.001998 | |

**Appendix J**

Table 7.8: vij=rij*wj

| | **vij=rij*wj** | | | | |
|---|---|---|---|---|---|
| **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| 0.00134 | 0.001338 | 0.002007 | 0.00067 | 0.001005 | 0.001673 |
| 0.00066 | 0.0016475 | 0.001648 | 0.00066 | 0.000825 | 0.001648 |
| 0.079191 | 0.0790822 | 0.079086 | 0.079193 | 0.079182 | 0.079106 |
| 0.000804 | 0.0076266 | 0.007226 | 0.001206 | 0.002411 | 0.006424 |
| 9.24E-05 | 0 | 8.3E-05 | 8.5E-05 | 8.22E-05 | 8.49E-05 |
| 0.00075 | 0 | 0.000749 | 0.00075 | 0.000938 | 0.00075 |

**Appendix K**

| | | **A*** | | | |
|---|---|---|---|---|---|
| **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| 0.00134 | 0.001338 | 0.002007 | 0.00067 | 0.00100478 | 0.001673 |
| 0.00066 | 0.0016475 | 0.001648 | 0.00066 | 0.00082482 | 0.001648 |
| 0.079191 | 0.0790822 | 0.079086 | 0.079193 | 0.07918243 | 0.079106 |
| 0.000804 | 0.0076266 | 0.007226 | 0.001206 | 0.00241146 | 0.006424 |
| 9.24E-05 | 0 | 8.3E-05 | 8.5E-05 | 8.2218E-05 | 8.49E-05 |
| 0.00075 | 0 | 0.000749 | 0.00075 | 0.00093779 | 0.00075 |

**Appendix L**

| | A' | | | | |
|---|---|---|---|---|---|
| **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| 0.001339846 | 0.001338 | 0.002007113 | 0.000669938 | 0.00100478 | 0.001673006 |
| 0.000659924 | 0.0016475 | 0.00164763 | 0.000659939 | 0.00082482 | 0.001648036 |
| 0.079190923 | 0.0790822 | 0.079086229 | 0.079192657 | 0.07918243 | 0.079105704 |
| 0.000803908 | 0.0076266 | 0.007225605 | 0.001205888 | 0.00241146 | 0.006424342 |
| 9.23894E-05 | 0 | 8.30405E-05 | 8.50001E-05 | 8.2218E-05 | 8.49068E-05 |
| 0.000750314 | 0 | 0.000749322 | 0.00075033 | 0.00093779 | 0.000749507 |

**Appendix M**

| | | | $S_{i*} = [ S_j (v_{j*} – v_{ij})_2 ]^{½}$ | | | |
|---|---|---|---|---|---|---|
| | **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| | -0.077851154 | -0.0777442 | -0.07707889 | -0.078523062 | -0.0781776 | -0.07743 |
| | -0.078531076 | -0.0774347 | -0.07743837 | -0.078533061 | -0.0783576 | -0.07746 |
| | 0 | 0 | 2.29199E-07 | 0 | 0 | 0 |
| | -0.078387092 | -0.0714556 | -0.07186039 | -0.077987112 | -0.0767709 | -0.07268 |
| | -0.079098611 | -0.0790822 | -0.07900296 | -0.079108 | -0.0791002 | -0.07902 |
| | -0.078440686 | -0.0790822 | -0.07833668 | -0.07844267 | -0.0782446 | -0.07836 |
| **Si* = Sj (vj*– vij)2** | **0.030782** | **0.029654** | **0.0294799** | **0.03082663** | **0.030524** | **0.02966** |
| **$S_{i*} = [ S_j (v_{j*} – v_{ij})_2 ]^{½}$** | **0.175448** | **0.172204** | **0.171697** | **0.17557514** | **0.174713** | **0.17223** |

**Appendix N**

| | | | $S_{i'} = [ S_j (v_{j'} – v_{ij})^2 ]^{½}$ | | | |
|---|---|---|---|---|---|---|
| | **Cassava** | **Sugarcane Bagasse** | **Jatropha** | **Palm oil** | **Sunflower** | **Neem** |
| | 0.001247457 | 0.001338 | 0.001924072 | 0.000584938 | 0.0009226 | 0.001588099 |
| | 0.000567535 | 0.0016475 | 0.001564589 | 0.000574939 | 0.0007426 | 0.001563129 |
| | 0.079098534 | 0.0790822 | 0.079003189 | 0.079107657 | 0.0791002 | 0.079020798 |
| | 0.000711518 | 0.0076266 | 0.007142565 | 0.001120888 | 0.0023292 | 0.006339435 |
| | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0.000657925 | 0 | 0.000666282 | 0.00066533 | 0.0008556 | 0.0006646 |
| **Sj (vj'– vij)2 =** | **0.0062594** | 0.0063167 | **0.00629911** | **0.00626039** | **0.006264** | **0.0062899** |
| **$S_{i'} = [ S_j (v_{j'} – v_{ij})^2 ]^{½}$** | **0.07911634** | **0.079477** | **0.07936696** | **0.07912265** | **0.079148** | **0.0793088** |

**Appendix O**

| **Ci* = S'i / (Si* +S'i )** | |
|---|---|
| **Cassava** | 0.3107911 |
| **Sugarcane bagasse** | 0.3157859 |
| **Jatropha** | 0.3161225 |
| **Palm oil** | 0.3106531 |
| **Sunflower** | 0.3117769 |
| **Neem** | 0.3152944 |

Figure 7.4: Crops and outputs per acre

| **Crop** | **Output /Acre** |
|---|---|
| **Cassava** | 8-10tons |

| | |
|---|---|
| **Sunflower** | 0.0015-0.002tons |
| **Neem** | 30.57tons |
| **Palm** | 7.7tons |
| **Jatropha** | 0.67-0.89 tons |
| **Baggase** | n/a |

Source: Author

**Appendix P**

**Budget**

| S/No. | Item | Unit | Quantity | Rate (Unit price) USD | GHS | DZD | Amount* ($) | Link to Research Activity** | Comment*** (For Evaluator Only) |
|---|---|---|---|---|---|---|---|---|---|
| **( A ) Material and Sup plies** | | | | | | | | | |
| 1 | e.g. ArcGIS software License | 1 | 1 | 100.00 | | | **100.00** | To evaluate the bioenergy development potential based on the availability of marginal land resources and the growing conditions of the energy plants within the data grid. | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2 | Communication and data bundles for (4 months) | 1 | 4 | 49.45 | **298.43263 GHS** | | **197.8** | For research, downloading articles and other resources relevant to the research work and also communication with supervisor about research | |
| | | | | | | | | on work progress | |
| 3 | Stationery, Printing, Photocopying, poster | | 4 | **102 USD** | **512.02907GHS** | | **102.00** | Printing, Photocopying and binding for submission. | |
| | **Sub Total** | | | | | | **706.32** | | |
| **( B) Equipment** | | | | | | | | | |
| 1 | GPS (GARMIN 64SC) | 1 | 1 | - | - | - | - | Data collection on marginal land resources | Collect from PAUWES |
| 2 | Mifi Hotspot Router Wi-Fi 4G LTE | 1 | 1 | **32.88112 USD** | **165 GHS** | | **32.88112** | For internet connection | |
| 3 | | | | | | | | | |
| | **Sub Total** | | | | | | **32.88112** | | |
| **( C ) Travel** | | | | | | | | | |
| **In ternational Travels** | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Flight ticket (Algiers- Accra) round trip | 1 | 1 | **1013.70895 USD** | | **125,000 DZD** | **1055.94682** | To the country of research. | |
| | **National Travels** | | | | | | | | |
| 2 | Algiers to Tlemcen (round trip) | 1 | 1 | **86.08923 USD** | | **10,191 DZD** | **86.08923 USD** | To the international airport to catch flight | |
| 3 | Flight ticket, Accra to Kumasi, Accra to Sunyani | 1 | 2 | **95 USD** | **476.88982** | | **190** | To the cities of data collection | |
| 4 | Internal travels (data collection) | 2 | 6 | **41.667 USD** | **209.16388 GHS** | | **250** | Transport within cities for data collection | |
| 5 | Travel Insurance | | | **60 USD** | | | **60** | | |
| | **Sub Total** | | | | | | **1642.035** | | |
| | **( D ) Special Activities** | | | | | | | | |
| 1 | e.g. Publication | 1 | 1 | 170 | | | **170** | 1. A working document for policy makers 2. Put PAUWES in the limelight 3. To provide more literature on the study for future work | |
| | **Sub Total** | | | | | | **170** | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **( E) Contingencies (%) optional** | | | | **100** | | |
| | | | | | | |
| | **TOTAL** | | | | | |
| A | Personnel (2) | **350 GHS *2** | | **139.44521** | | |
| B | Material & Supplies | | | **706.32** | | |
| C | Equipment | | | **32.88112** | | |
| D | Travel | | | **1642.035** | | |
| E | Special Activities | | | **170.00** | | |
| F | Contingencies (%) - optional | | | **100** | | |
| | **Grand Total** | | | **2790.68133** | | |