PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

Energy Engineering

Prepared by: **Dominique Savio BARAHIRA**

FEASIBILITY STUDY AND ENERGY APPLICATIONS OF ADVANCED (2G AND 3G) BIOFUELS IN SOUTH AFRICA

Defending on 05/09/2019 before the Following Committee:

Chair	Dib Amazigh	Doctor	Pan African University (PAUWES)
Supervisor	Andrew c. Eloka-Eboka	Doctor	University of KwaZulu-Natal
External Examiner	Chakib Seladji	Professor	University of Tlemcen
Internal Examiner	Negadi Latifa	Professor	University of Tlemcen

DECLARATION-1-STATEMENT OF THE AUTHOR

I, Dominique Savio BARAHIRA, hereby declare that this dissertation represents my personal work, realized to the best of my knowledge. I also declare that all information, materials and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics. This is the original work, which have never been submitted before for the purpose of being awarded a degree in any University.

Signed:

Dominique Savio BARAHIRA

DECLARATION-2 – PUBLICATIONS

(1) **Dominique S. Barahira,** Andrew C. Eloka-Eboka and Vincent I. Okudoh (2019). Suitability of crop residues as feedstock for biofuel production in South Africa: A win-win scenario. Renewable and Sustainable Energy Reviews – ***Elsevier: Submitted and in Review***

(2) **Dominique S. Barahira,** Andrew C. Eloka-Eboka and Vincent I. Okudoh (2019). Crop waste to bioenergy in South Africa: A win-win scenario: International Conference on Green Energy and Recycling, December 2nd to 3rd, 2019, Berlin, Germany. ***Accepted for presentation and proceeding publication.***

For all publications, the student is the main author while Dr. Andrew Eloka-Eboka and Dr. Vincent Okudoh are supervisors.

CERTIFICATION

As candidate's supervisors, we approved this dissertation for submission and examination

Signed: ______________________ Signed:

Dr. Andrew C. Eloka-Eboka — *Supervisor*

Dr. Vincent Okudoh — *Co-Supervisor*

ACKNOWLEGMENT

I thank the Almighty God for strength, wisdom, understanding and good health during my study at the Pan African University Institute of Water and Energy Sciences (including Climate Change). My sincere gratitude goes to the African Union through the African Union Commission (AUC) and all the partners of the PAUWES project for granting me the opportunity to undertake this master degree program at PAUWES. Also, my appreciation goes to the AUC who provided me with research grant to carry out this research work. Furthermore, my profound appreciation goes to my supervisor, Dr. Andrew Eloka-Eboka, of the Discipline of Mechanical Engineering, University of KwaZulu-Natal who took time out of his busy schedules to read through my bulky literatures and provided the best information to reshape this thesis to the present admirable form. I also thank my Co-supervisor, Dr. Okudoh Vincent from Cape Peninsula University of Technology who accepted to take me as his research intern for a six-months period; everything went smoothly on my side because of his efforts, I will forever be grateful. Last but not the least; I thank my parents, siblings, colleagues and friends for their effective and consistent prayers, love, support and encouragements during my study. You got my love back.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

AUC	Africa Union Commission
BTL	Biomass to Liquid
EU	European Union
GHG	Green House Gases
PAUWES	Pan Africa University, Institute of Water and Energy Sciences
RPR	Residue to Product Ratio
2G	Second Generation
3G	Third Generation
SA	South Africa
SCC	Social Cost of Carbon
SDG	Sustainable Development Goals
USA	United States of America

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS OF KEY TERMS

Advanced biofuels	Are fuels which are produced or which can be generated from renewable biomass feedstock sometimes referred as lignocellulosic feedstocks such as crop residues, food waste, biodegradable municipal solid waste, forest residues, purposely grown energy crops, aquatic plants such as sea weeds and algae [1, 2].
Feasibility study	A feasibility study is a study, which involves an evaluation of, technical, economic and financial viability of a certain undertaken project. In biofuels context the study has to find out even environmental aspect of sustainability.
Biomass	From a scientific and technical point of view, biomass is a material of biological origin excluding material embedded in geological formations and/or transformed to fossil.
Bioenergy	The energy produced from biomass.
Biofuels	It is a fuel produced directly or indirectly from biomass. There are solid, liquid, and gaseous biofuels. The most known liquid biofuels are biodiesel and bioethanol.
Sustainable development	Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Biofuel program	In general, encompasses incentives to biofuels production and/ or consumption through policies and regulatory frameworks.

ABSTRACT

Recent advancements in the technology, economy and sustainability of bioenergy from biomass and biofuel have been revolutionized. There is the utmost need for the sustainability of bioenergy and in transmogrifying the approaches to sourcing, production and overall applicability and thus the intensification of socio-economic impacts of the use of biofuels as bioenergy source in different energy sectors of the global economy. Albeit, in the production and generation of biofuels from food crops and feedstocks, there has been intercontinental technological logjam as the stream of food, water vs energy chain becomes threatened. Production of bio-energy from food crops and feedstocks poses immense pressure on food sustainability with attendant competitive consequences. There are indirect and direct environmental impacts associated, mostly stressing the soil, land and water when cultivating and growing the energy crops and feedstocks. There is no doubt that advanced biofuels will overcome this threat and challenges especially in Africa as this monotonous dependence will be eliminated. Feasibility study of advanced biofuels and energy applications is required to boom biofuel industry in South Africa. A technique called residue to product ratio was used to generate data on crop residues potentially available to produce advanced biofuels. Excel spreadsheet was used for results analysis. About 13.5 Mt of crop residues from 19 crops were made available which can generate 4.9 GL of bioethanol per year using biochemical route conversion technology. This study will impact on policy development in biofuel sector by government of South Africa. It will also help potential investors willing to embark on advanced biofuels. The outcome can also be used as a model for Africa as a whole.

Keywords: Feasibility study; Advanced biofuels; Bioenergy; South Africa; Crop residues.

RESUME

Les progrès récents dans la technologie, l'économie et la durabilité de la bioénergie issue de la biomasse et du biocarburant ont été révolutionnés. Il est absolument nécessaire de préserver la bioénergie de manière durable et de transformer les approches en matière de sourçage, de production et d'applicabilité globale, et donc d'intensifier les impacts socio-économiques de l'utilisation de biocarburants comme source de bioénergie dans différents secteurs énergétiques de l'économie mondiale. Même si, dans la production et la production de biocarburants à partir de cultures vivrières et de matières premières, il existe une impasse technologique intercontinentale lorsque le flux de denrées alimentaires, de l'eau par rapport à la chaîne énergétique devient menacé. La production de bioénergie à partir de cultures vivrières et de matières premières exerce une pression immense sur la durabilité des aliments, avec les conséquences concurrentielles que cela entraîne. Il y a des impacts environnementaux directs et indirects associés, qui stressent principalement le sol, la terre et l'eau lors de la culture et de la croissance des cultures énergétiques et des matières premières. Il ne fait aucun doute que les biocarburants avancés permettront de surmonter cette menace et ces défis, en particulier en Afrique, dans la mesure où cette dépendance monotone sera éliminée. Une étude de faisabilité sur les biocarburants avancés et les applications énergétiques est nécessaire pour faire exploser l'industrie des biocarburants en Afrique du Sud. Une technique appelée rapport de résidus au produit a été utilisée pour générer des données sur les résidus de cultures potentiellement disponibles pour produire des biocarburants avancés. Un tableur Excel a été utilisé pour l'analyse des résultats. Environ 13,5 Mt de résidus de récolte provenant de 19 cultures ont été mis à disposition. Ils peuvent générer 4,9 L de bioéthanol par an en utilisant la technologie de conversion biochimique par voie. Cette étude aura un impact sur le développement de politiques dans le secteur des biocarburants par le gouvernement Sud-Africain. Cela aidera également les investisseurs potentiels disposés à se lancer dans les biocarburants avancés. Les résultats peuvent également servir de modèle pour l'Afrique dans son ensemble.

Mots Clés : Etude de faisabilité ; Biocarburants avancés ; La bioénergie ; Afrique du Sud ; Résidus de récolte.

CHAPTER ONE: INTRODUCTION

1.1 Background

Driven by sustainable development goals (SDGs), precisely the goal number seven (SDG7), Africa as a continent aimed herself to attaining sustainable energy for all at the dawn of 2030. The agenda 2063 is a long-term vision by which different programs has to be executed including that of bringing safe, clean and affordable energy for all in order to achieve all-inclusive sustainable development in the continent [3]. Energy is the foremost pillar in the development of any nation [4]. Therefore, African nations have to do everything possible to ensure sustainable availability of clean, affordable and safe source of energy carriers.

The main source of fuel for many developing countries in Africa come from traditional biomass [5]. The use of biomass in traditional ways have many associated negative effects: social and ecological like indoor air pollution which poses risks for women's health, burden for them and their children who collect fuel for their homes, and loss of biodiversity[6-8].

Few African countries have fossil fuel reserves and projections show that their depletion is alarming in future [9]. Climatic change and its associated effects are attributed mostly to the burning of fossil fuels Which is responsible for greenhouse gases (GHG) [10], hence a question mark has to be placed on the use of this type of energy. Alternative sources of energy are required for easing the burdens accompanying the use of conventional fuels especially for African nations.

There exists many renewable energy sources: hydro, thermal, nuclear, wind, solar and bioenergy [11] which have potentials to alternate or substitute fossil-based types of energy. Among the listed renewable sources of energy, only bioenergy has the potential to replace liquid fuels derived from fossil fuels [12]. The sustainable use of bioenergy is therefore very crucial in playing useful roles and impact in Africa.

Bioenergy is a source of renewable energy derived from solid and liquid biomasses [13]. Energy from biomass has been used in Africa traditionally many years ago back in history [14] until now. With the increase in technology, today, it is the right time to incorporate modern technology in the harvesting, use and several applications of biomass. Different approaches to improve the use of biomasses technologically are being explored globally, which include generating biofuels from different biomasses. Biofuels can be blended with other fuels like petrol or can be used alone to drive different sectors of economy worldwide [15].

Biofuels can be generated from different sources including food crops, crops residues, purposely grown energy crops, municipal wastes, switch grasses, algae to name but a few [16]. Biofuels generated from biomass food crops feedstocks are called first generation biofuels [17]. Debate of food versus fuel has been raised by scientists, stakeholders and users since the advent of renewable energy incursion [18]. Mueller et al. [19] observed that the food prices that increased in 2007 and 2008 and onwards was due to the utilization of food crops in biofuel production. Worldwide, researchers are trying to find solutions to this dilemma of food competition with energy by developing several technologies and searching for compromising feedstocks, which also include the concept of advanced biofuels and the dynamics involved.

Advanced biofuels are fuels produced from non-edible food crops or from wastes or from secondary recycled products of product processing that are sustainable. They are giving hope of being one of sustainable solutions. There is hope that they will overcome food security and energy conflict and at the same time help save the environment and avert greenhouse gas epidemic currently threatening the globe [20]. Efforts are encouraged to develop technology suited for advanced biofuel production from several sources as long as they are sustainable.

There are barriers associated with the use of advanced biofuels, which include: immature technology, availability of reliable feed stocks, policy instruments and implementation among others. In the work completed by Mohr and Raman [21], it was pointed out some challenges which may arise when transition from first to second generation biofuels will be adopted with little or no attention payed to their feasibility study.

Advanced biofuels need a deep study in order to be commercially viable**,** economically supported and environmentally sound. For this to happen, feedstocks must be available sufficiently and on regular basis and at reasonable costs, if possible, for free. Therefore harvesting, transportation of feedstocks and storage must bear minimum cost in order to limit the production cost of biofuels [22].

Advanced biofuels have been commercialized by building pilot plant for the first time in USA, followed by China and Canada, later in EU (France and Germany) and Brazil respectively in 2015. There have been policy instruments to support the advancement of advanced biofuels in those countries leading the market. Africa as well as Latin America in exception of Brazil remains inept on projects revolving around cellulosic biofuels [23].

This research conducted a feasibility study of advanced biofuels and their energy potentials and applications using South Africa as a case study and benchmark from available and generated feedstocks.

1.2. Problem Statement

Energy diversification, security of supply, import substitution, food security and climate change mitigation are the main drivers, which are creating interest in the development of biofuels from different biomass feedstocks. However, producing biofuels from food crops is not being regarded as a wise way of achieving the above drivers when bearing in mind that African continent is full of hungry-prone because of food security issue around the world. Research-and-development activities on renewable biofuels so far have been undertaken only in a number of developed countries (USA, EU) and in some large emerging economic countries like Brazil, China and India and in few African countries. Feasibility study and energy applications of advanced biofuels in South Africa will contribute to the development and use of biofuels from renewable resources in the continent. There are no such studies on the feasibility of biofuels or biomass energy quantification conducted in Africa. The present research will fill the gap.

1.3. Aim

The aim of this study is to conduct a feasibility study and energy applications of advanced biofuels feedstocks in South Africa.

1.4. Objectives

1. To characterize potential crops which are able to generate residues for biofuel production in South Africa.
2. Quantification of crop residues available for sustainable biofuel production in South Africa.
3. Quantification of Energy yield per year from crop residues for advanced biofuels production in South Africa.
4. To carry out life cycle analysis and sensitivity analysis for potential crop residues in South Africa.

1.5. Research Questions and Hypotheses

A. **Questions**

1) What are the potential crops capable for generating enough residues to produce advanced biofuels in South Africa?
2) At what extent theoretical cellulosic ethanol produced from crop residues can replace fossil fuels (gasoline) consumed in South Africa?
3) Is it possible to mitigate climate change by using cellulosic biofuel produced from crop residues in South Africa?

B. Hypothesis

1) Varieties of crops are available to generate residues for producing advanced biofuels in South Africa
2) Cellulosic ethanol is potentially capable of replacing fossil fuels being used in South Africa.
3) It is practically possible to mitigate climate change by using advanced biofuels.

1.6 Significance of the Research

A. The data generated will be helpful for potential investors in the biofuel industry
B. The government will make informed decisions regarding policies to support the development of advanced biofuels
C. Future researchers will rely on data generated in this research for further research and development in the biofuel sector

1.7. Delineation of the Study

The study was focused mainly on advanced and sustainable feedstocks for biofuels production and utilization from crop residues generated in South Africa and using transport to evaluate energy application

1.8. Thesis Chapter Layout

- Chapter One: Introduction: This chapter provides the background of the study; it states the research problem of the study, aim and objectives of the study, research questions, hypothesis, significance of the research and research delineation. It also gave an insight into the rationale or motivation for venturing into this research.
- Chapter Two. Literature Review: In this chapter, global overview of advanced biofuels is covered. It highlights the profile of South Africa and its energy sector overview. Advanced resources for biofuel productions in South Africa are introduced. Technologies for harnessing advanced biomass resources are presented.
- Chapter Three: Materials and methods: This chapter lists materials, tools and methods and techniques used in the study to quantify advanced biomass resources available in South Africa.
- Chapter Four: Data presentation, results and discussion: This chapter comprises the data generated and discussion on their implications for energy applications and lastly,
- Chapter Five: Conclusions and Recommendations: This chapter provides a summary of the study, recommendations; answers to questions presented in chapter one and concluded the study.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

In this chapter, we presented the global context, continental and national biofuel situation and current available technologies for converting advanced feedstocks into liquid fuels.

2.1 Biofuels in the Global Context

2.1.1. Biofuel brief trajectory

Globally, national biofuel programs have been introduced. Firstly, for the supply security and secondly, to lessen massive trade shortages caused during 1973-year oil price shocks [24]. Brazil was the leading country, which now generates about 50% of its gasoline needs as ethanol using sugar cane [25], either blended as E85 or E20-25 [26].

The USA program of producing ethanol from maize which generates similar quantities to Brazil [27], or around 1.5 compared to South African gasoline use was largely urged by market expansion for maize beyond foodstuff and industrial use of alcohol, and to provide air quality uses and supply security [28].

Biofuel programs are becoming popular worldwide, apart from substituting imported crude oil. In theory, this can reduce greenhouse gas emissions [29]. Accordingly, they have received massive fiscal support, primarily through reduced fuel levies [30]. Fuel levies of up to R4.50 per liter are common in Europe, and exemptions of up to 100% are typical [31]. Germany, a European leader in biodiesel, has achieved a 2% of biofuels market plan. However, due to the increase in tax losses, Germany has lately re-introduced biodiesel tax. Biofuels have higher potential job-creation by a factor of 100 compared to the job created from refining of imported crude oil [32].

2.1.2 Brazilian experience in the biofuel sector

The Brazilian experience shows that the biofuel benefit is derived from the co-production of ethanol and electricity using sugar cane bagasse [33]. The bioethanol produced from sugar cane bagasse industry has net energy balance, as it produces its own energy without an additional load in the national grid [34]. The success of biofuels differs from one country to another and mostly depends on the support from government. However, long period investments and increase in efficiency have played important role in Brazil's case [35].

2.1.3 Lessons to learn from first generations biofuels

2.1.3.1 First generation biofuels and food conflicts

First generation biofuels are based on producing fuels from crops. This is seen as a big challenge as the stream for food-water-fuel chain is threatened. Emerging research evolved at the end of twentieth century are meant to harvest biomass for fuel production in a sustainable manner. The experience gained from first generation will help in introducing advanced biofuels (second and third generations) where fuels are generated from biomass wastes or purposely energy grown crops hence reducing if not eliminating completely the challenges associated with first generation biofuels [17].

Sustainability issues, which have been raised against first generation biofuels, may also be applied on advanced biofuels. First generation biofuels being produced directly from food crops have been attributed as the root cause of rising food prices. Food shortage period occurred between (2007-2008) and had consequences on many food crops especially grain crops which are the main feedstocks for first generation biofuel production [36]. Should advance biofuels revolve around the feedstock in connection with first crops, more debate for indirect food versus fuel will arise if those feedstocks are already being utilized for other purposes like animals' feeds and other chemical process needs.

Growing biofuels production feedstock like energy crops can be associated with environmental concerns related to water pollution, biodiversity distraction, and indirect land use change [37]. It is important to minimize negative effects associated with the production of advanced feedstock as much as possible and maximize their pros. The appraisal of advanced biofuels in job creation for rural farmers, energy diversification, import substitution, security of supply and CO_2 reduction in atmosphere are the points to consider in advocating or supporting the policy regarding advanced biofuels introduction [17, 38].

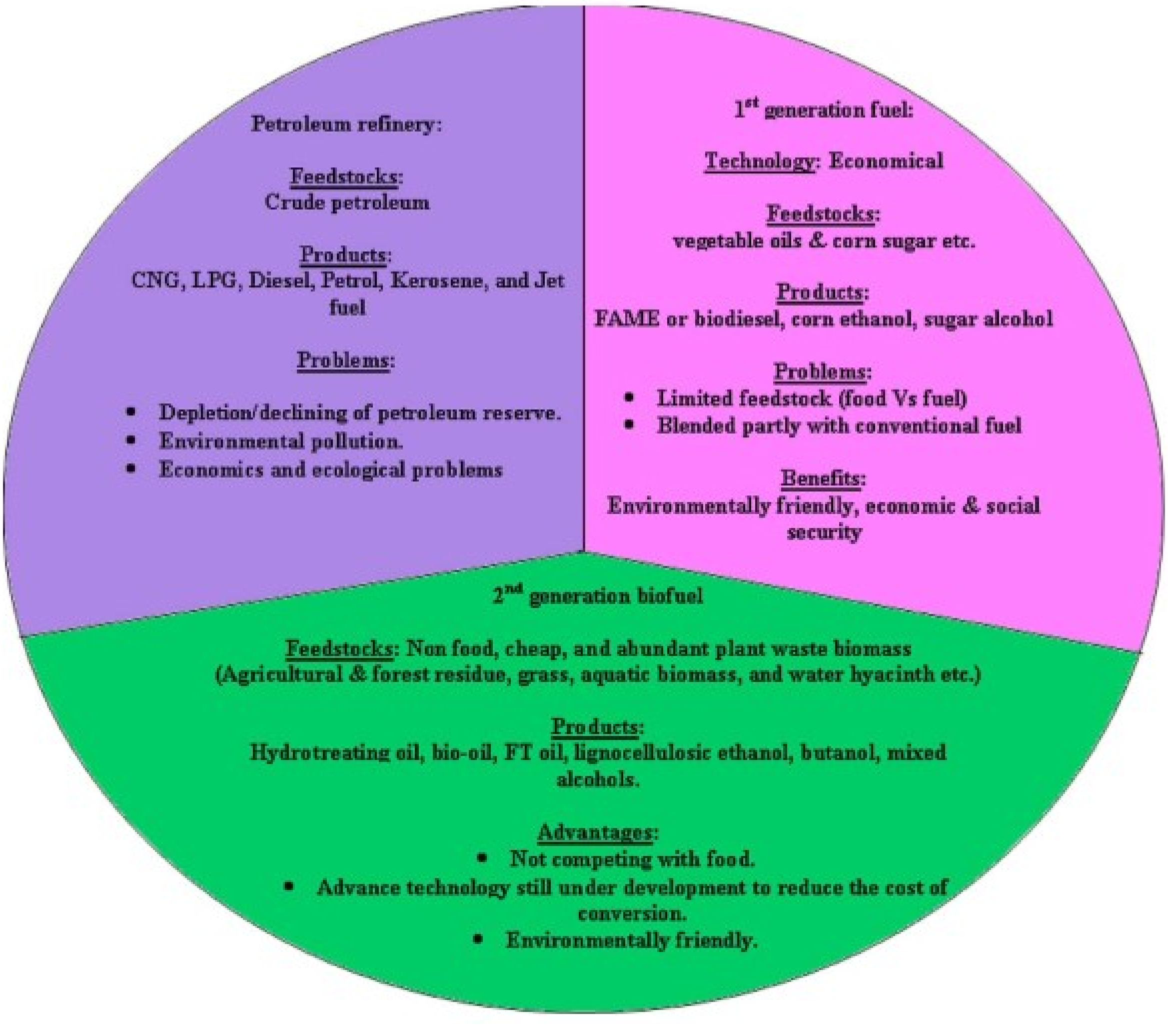


Figure 1:Comparison of fossil fuels, first generation and advanced biofuels(Source: Adapted from [17])

Also when considering the interlink between food and energy, advanced biofuels are appraised as they are able to provide energy required for growing food crops [21]. Therefore, it is important to consider each element in the life cycle analysis in appraising the sustainability of advanced biofuels based on experiential evidence learned from the first and second-generation biofuels.

Importing fossil fuel products is a burden almost to all African countries. Renewable energy including bioenergy in African is seen as solutions which will help the continent to be energy secured and reliant [39]. Africa has potentials to develop bioenergy industry that will sustain even the entire globe more than Europe and America. The African climate and the soil are both favorable in growing energy crops [40]. But the agricultural sector in Africa is poorly managed. Advanced biofuels can help to stimulate agriculture in Africa by promoting commercial and large-scale agriculture thus providing energy and food in juxtaposition with one another.

Southern Africa has shown interests in biofuel production compared to other African regions. There is a renewable energy master plan in place to be implemented. Zimbabwe and South Africa are the leaders in ethanol production based on sugar cane products and only Zimbabwe has sustained its production and consumption with E10-E15 blend mandate into petroleum products. As illustrated in Table 1, showing bioenergy policy initiative in some African countries, some countries have strategized policies that support biofuels production already.

Table 1: Bioenergy policy initiative in some African countries (Source: [41])

Country	Policy initiative	Opportunities / comments
Ethiopia	"National biogas programs, which plans to build 14000 domestic biogas digesters. A 50 % blending of petrol and ethanol since 2008".	"Under the national biomass program, a 4-year demonstration project has demonstrated notable benefits of replacing fuelwood (currently 29%) and kerosene (42 %) with ethanol stoves; notably reduced foreign exchange to import kerosene, reduced distanced travelled to collect firewood by 70%, and improved indoor air quality"
Ghana	"Jatropha oil for mixing with diesel (70% plant oil/30% diesel) to fuel butter processing equipment, and as a kerosene substitute for use in lanterns".	"Village -level biofuel production. Note: Jatropha has been planted in a number of other African countries such as Malawi and Mozambique (see below) as well as Mali. In South Africa currently only allowed for experimentation"
Kenya, Tanzania, and Uganda	"Afforestation for sustainable charcoal production"	"Charcoal making supports about 500,000 full time and part-time charcoal producers. Wood fuel demand is double the supply, with forest cover decrease by 2% annually, thus incentive for tree planting. Charcoal remains preferred choice over briquettes despite higher price and more pollution".
Madagascar	"Ethanol as a household fuel and alternative sources of energy to relieve the pressure on forest resources and reduce childhood mortality"	"Identified need for a regulation, Government support and optimization identified as key requirements for success"
		"Identified need for economic sustainability"
	"Gel fuel to replace charcoal as a cooking fuel in urban areas"	
Malawi	"Restoration and commercial use of tree crops, including marginal lands"	"Potential for integrating various tree species to increase crop yield, rehabilitate degraded land, and improve the soil fertility. Products are used as bio fertilizer and green charcoal"

Table 1: Continues

Country	Policy initiative	Opportunity/comments
	Power accounts for 30% of total electricity demand in the country "	Alternative to 100% coal imports"
Mozambique	Initiated in 2004, biofuel production originally dominated by small-scale farmers, now by foreign commercial investors	Originally the focus was primarily on jatropha biodiesel, now there is increased emphasis on bioethanol derived from sugar cane and sorghum
South Africa	"Mandatory blending of petrol and diesel with biofuels as follows: 5% minimum concentration for biodiesel blending and permitted range for bioethanol blending from 2% to 100% v/v. Targeted date was October 2015"	"South African Airways plans 50% use of aviation biofuels by 2020.Energy crops includes sweet sorghum and sugarcane. Renewable energy feed-in tariff implemented to establish energy prices including a profit margin to attract developers to invest".
Tanzania	"Social biogas. Conventionally only 4% of the plant (fiber) has been used to make items such as ropes and carpets. Two projects to date resulted in improved efficiency for biogas and biofertilizer production; current electricity output is 150 kw with plans to expand to other estates for a total of 6 MW"	"A private company without external supports leads this initiative, which led to an 80% increase in the number of children attending school, while access to health care also improved as a result of the energy supplied to schools and hospitals."
Zimbabwe	"Planned current 5% blending of ethanol in petrol to 15%"	"The technical feasibility and potential were demonstrated when the commercial producer reached maximum generation capacity of 18MWe. About 8 MWe is used for sugarcane ethanol, leaving 10MWe surplus."
	"Jatropha cultivation for biodiesel"	"Objective is to produce biodiesel to meet 10% import substitution (approximately 100 million L per year) from jatropha, using an existing facility operating on cotton and sunflower seeds."

Despite the obvious importance on the contribution in the development that biofuels might bring to African economy, and the current fuel versus food debate, there is still little efforts in research and development in embracing and sustaining the production of biofuels in Africa. Strong energy governance and clear policies on how biofuels can be embraced to help Africa to attain its sustainable development in different economic sectors as highlighted in the SDGs, will be the key to the development of advanced bioenergy.

Liquid fuels contribute significantly a huge energy part in the transport sector when compared to other sectors of the economy. Transport sector is the main contributor in greenhouse gas (GHG) emissions when engines burns out fossil fuel products. About 21% of the GHG emissions in the European union (EU) transport sector, and approximately 90% of the emissions are from road transport [22]. Alternative source of liquid fuels like biofuels will be a golden opportunity and same time, a solution among others.

2.1.3.2 Fist generation biofuels and sustainability

Biofuel potential in reducing GHG emissions can be achieved only if its net life cycle from production to its end use is taken into account and approved to be sustainable. The concept of sustainability is composed of three parameters: social, environmental and economic variables as shown in Figure 2 [42].

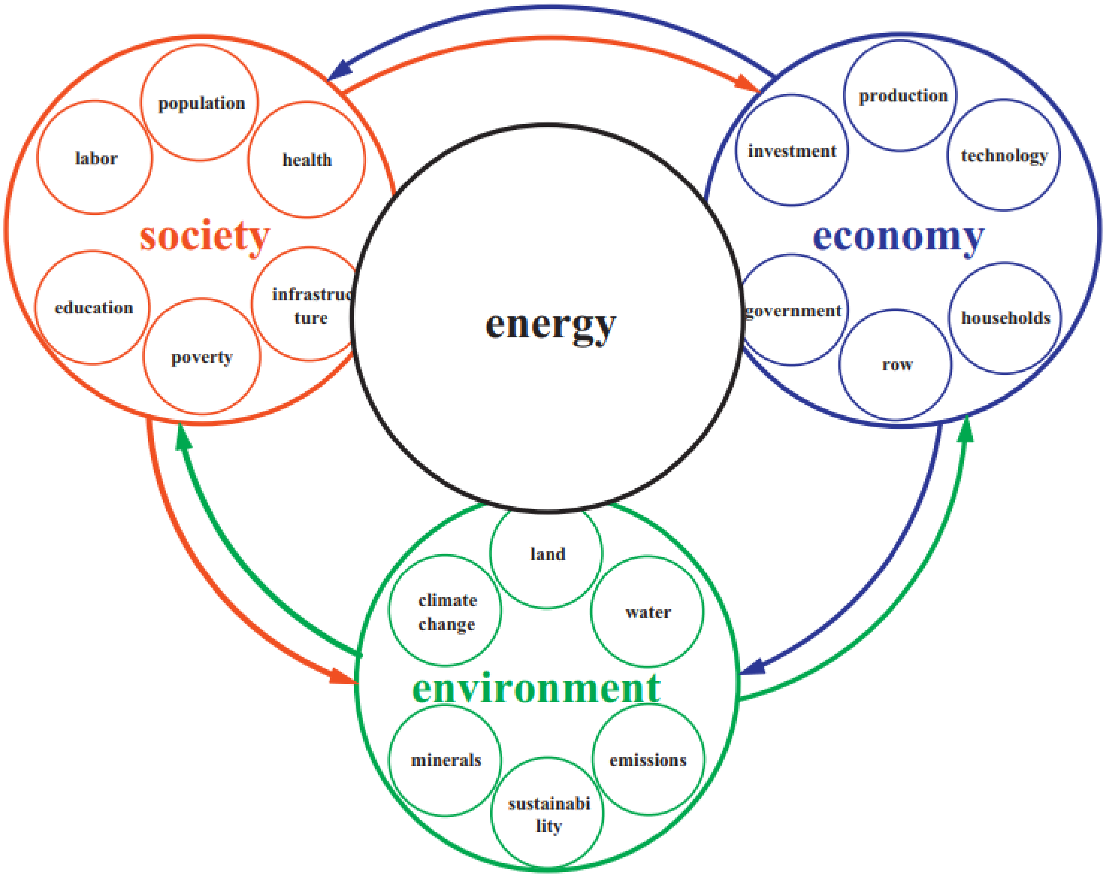


Figure 2: Energy and sustainability (Source: Adapted from[8])

First generation biofuels which are commercially available worldwide are regarded as non-sustainable [21, 43]. They are not fulfilling those three mentioned parameters directly or indirectly. They have social concerns because of using food crops as their feedstocks. Advanced biofuels do not have such social concerns as they utilize non edible food crops and wastes or residues as fuels [43].

Modern bioenergy development in Africa is one of the tools, which policy makers can use to attain one of the global Sustainable Development Goals for Africa. Bioenergy can improve social wellbeing by creating jobs especially in disadvantaged rural areas, helping rural women to be free and do not spend their whole life only for collecting fuelwoods for their homes but using the time for other productive works, and by bringing safe and clean fuel that will help in bringing income generating activities while also preserving the environment.

Bioenergy also can reduce importation costs related to petroleum products hence speeding up or boosting a nation's economy. Advanced biofuel production feedstocks like switch grass can help in increasing productivity by fixing carbon dioxide in the soil. Advanced biofuels can impact on environment by reducing GHG especially CO_2 emissions in the atmosphere [41, 44].

The most important issue which is compelling researcher to explore other technologies of harvesting biomass or using biomass sustainably is because first generation biofuels are solving one problem but causing or raising many others as illustrated in Table 2.

Table 2: Pros and Cons of first-generation biofuel (Source:[23])

Pros	**Cons**
"Simple and well-known production methods"	"Feedstocks compete directly with crops grown for food"
"Familiar feedstocks"	"By-products Production need markets"
"Scalable to smaller production capabilities"	'High cost feedstocks lead to high-cost of production (except Brazilian sugar cane ethanol)"
"Fungibility with existing petroleum-derived fuels"	"Low land use efficiency"
"Experience with commercial production and use in severalcountries"	"Modest net reduction in fossil fuel use and green gas emmissions with current processing methods (except Brazilian sugar cane ethanol)"

Ethanol fuel is the fuel produced in most countries using food crops from mostly starchy and sugar cane crops and the outcome frrom most countries are illustated in Figure 3.

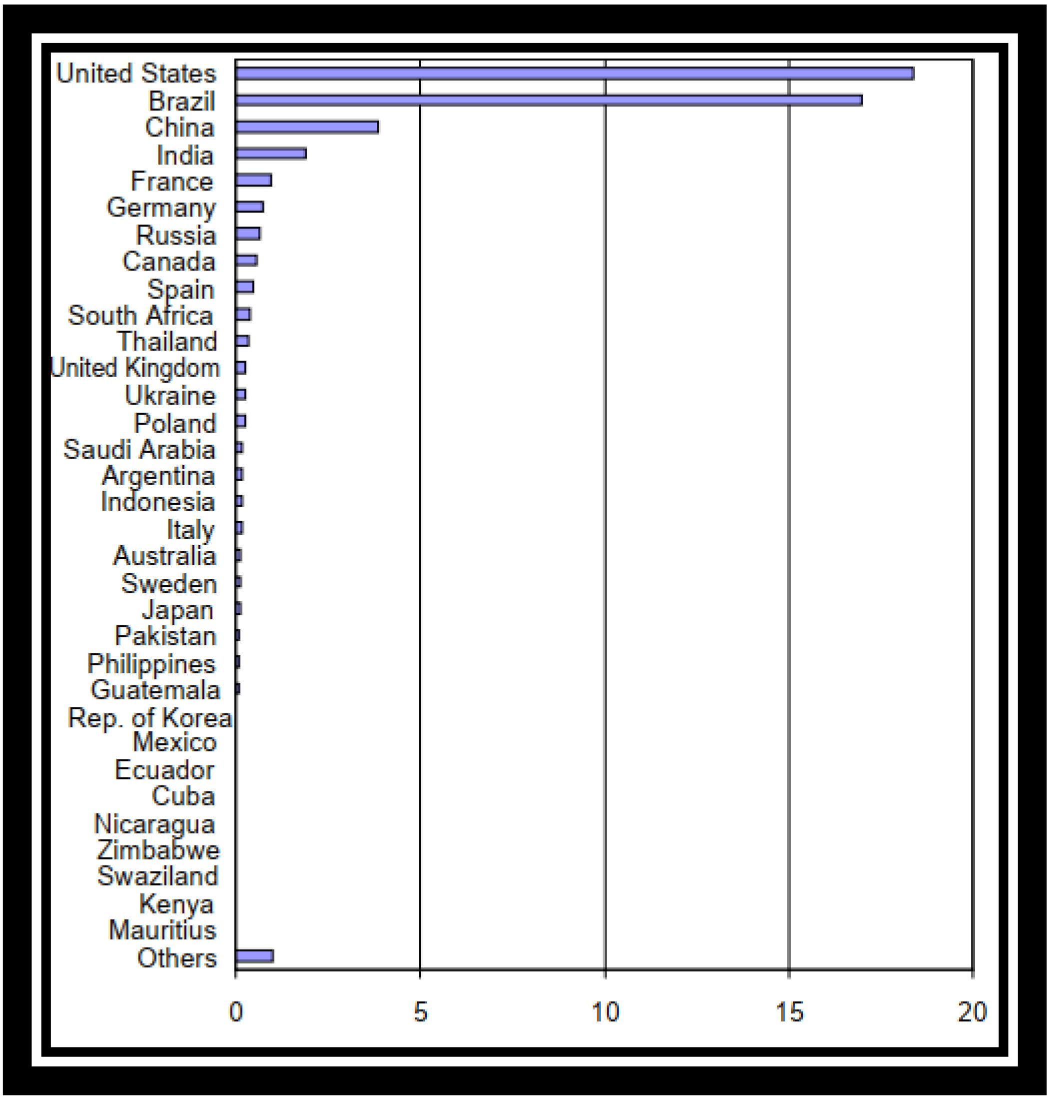


Figure 3: Ethanol produced in 2006 by selected countries (Source: Taken from [23].)

As of 2006, the global leading contributor in ethanol production is USA, followed by Brazil. South Africa being the first African ethanol producer on the list is followed by Zimbabwe. Biofuels produced in USA is mainly from corn-starch, the one from Brazil is based on sugar cane while production in Europe of biodiesel is based on rapeseed oil.

2.14 Energy Crops as Biofuel Feedstocks

Feasibility of advanced biofuels lies on their feedstock availability at low cost. The supply chain of biomass feedstocks from the point of collection (in the farm) to the processing plant has significant impact on the price of the final product (fuel). Hence, crop residues, forest and wood wastes; food wastes to limit a list must be available and easily accessible at reasonable cost including the transport cost and also sustainable.

Energy crops grown on marginal or abandoned land can help to generate biomass feedstock at low cost and avoid direct competition with other crops. However, the oil content of any crop grown on less fertile soil will be lower than that grown on well fed or suitable soil [45]. This means that to have the same quantity of oil, huge amounts of feedstocks will be needed which will translate to higher cost of feedstocks. Technology in agriculture, like plant breeding and pest control, can result in higher production of food crops for the same unit of land, hence generating space to grow energy crops [20]. The quantity of land needed to obtain feedstock from certain quantity of oil required is shown in Table 3.

Table 3: Land Area required for feedstock production (Source:[20])

Type of plant	**Plant capacity ranges, and assumed annual hours of operation**	**Biomass fuel required, (oven dry tonnes /year)**	**Truck vehicle movements for delivery to the plant**	**Land area required to produce the biomass (% of total land within a given radius)**
Small pilot	15 000-25 000 l/yr, 2000 h	40-60	3-5/yr	1-3% within 1 km radius
Demonstration	40 000 – 500 000 l/yr., 3000 h	100-1200	10-140/yr	5-10% within 2 km radius
Pre-commercial	1-4 Ml/yr, 4000h	2000-10 000	25-100/month	1-3% within 10 km radius
Commercial	25-50 Ml/yr., 5000 h	60 000- 120 000	10-20/day	5-10% within 20 km radius
Large commercial	150-250 Ml/yr, 7000 h	350 000-600 000	100-200/day and night	1-2 within 100km radius

2.3. Biomass Resources in South Africa

2.3.1 Country profile

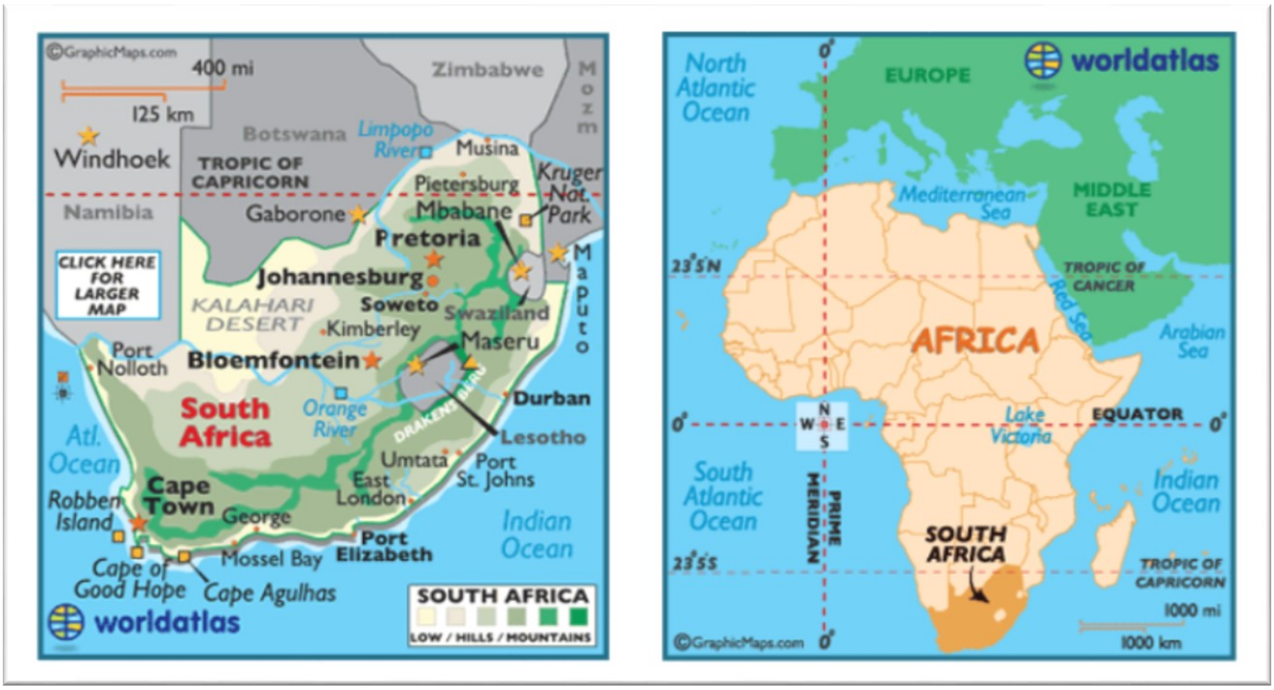


Figure 4: Continental location of South Africa(Source: [46])

The Republic of South Africa is located on the southern tip of Africa and lies between latitude 22° to 35° S, and longitude 17° to 33° E [46]. The land area of South Africa is 1,214,470 square kilometers and water covers about 4,620 square kilometers of area. This ranks the country as the 25th largest nation in the world with 1,219,090 square kilometers of total area. Indian Ocean and South West by Atlantic Ocean border South Africa in the South East. On the North West, it is bordered by Namibia and Botswana, in the North, by Zimbabwe and Mozambique. Inside South Africa, there are two land locked countries, Lesotho and Swaziland.

South African climate is classified as semi- arid; the western part receives less than 200 mm of precipitation in a year. South Africa has a wider variety of climate as well as topography than most other countries in sub Saharan [47]Africa, and it has a lower average temperature within the range of latitude, like Australia, because much its interior plateau are at higher elevation. South Africa is regarded as a sunny country, and enjoys 8 to 10 hours of sunshine on an average day. The South Africa annual average rainfall is about 464 mm when compared to the global average of 860 mm. South Africa has an estimated population of about 57 million in 2017 [47]. The population of South Africa constitute of 51% of female and 49% male, with a life expectancy of 67.3 years and 61.1 years respectively. The age pyramid of South Africa shows that 29.5% of the population is young and are above 15 years while 8.5 % of the population is older and are above 60 years.

South Africa is an upper-middle-income economy. It is the world's largest producer of platinum, and a major producer of gold, and chromium. About 24 percent of Africa's gross domestic product (GDP) comes from South Africa with major industries comprising, mining, automobile assembly, textile, iron and steel, chemicals, fertilizers, ship repair, and food production [48].

2.3.2 Energy situation in South Africa

South Africa energy sector is dominated by coal which occupies 59 %, followed by renewables and wastes for a 20% share; crude oil comes on a third rank with 16%, while gas comes with 3% and then finally nuclear with 2 % (Figure 5).

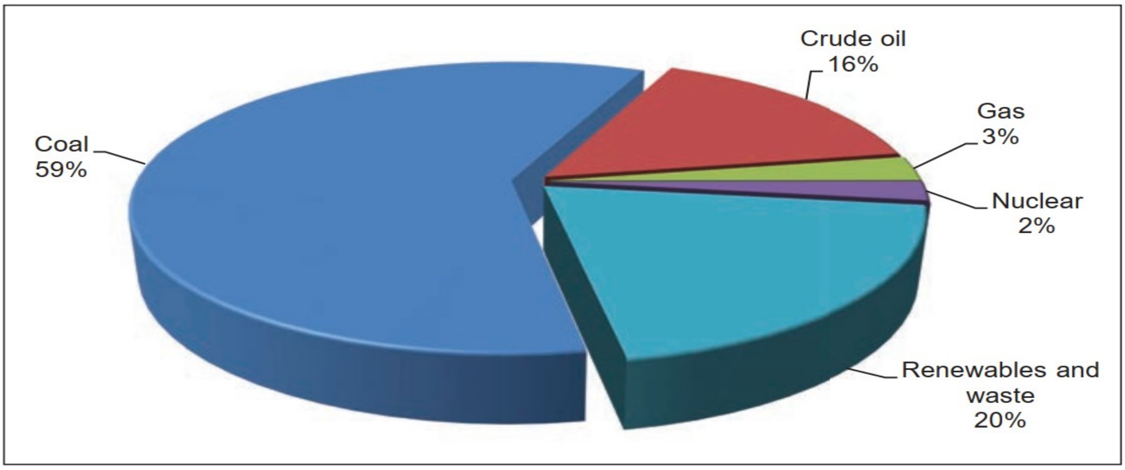


Figure 5: South Africa Energy mix (Source :[49])

The country produced its liquid fuels from two technologies: Gas to Liquid (GTL) and Coal to

Liquid (CTL) on 5 % and 39 % respectively as of 2015. The rest percentage come from crude oil [49]. Majority of petroleum products such as (petrol, diesel, residual fuel oil, paraffin, jet fuel, aviation gasoline, liquid petroleum gas) are synthetized or refined in the country. However, in order to meet South Africa domestic energy demand, about 83% of petroleum products are imported from outside the outside (Figure 6).

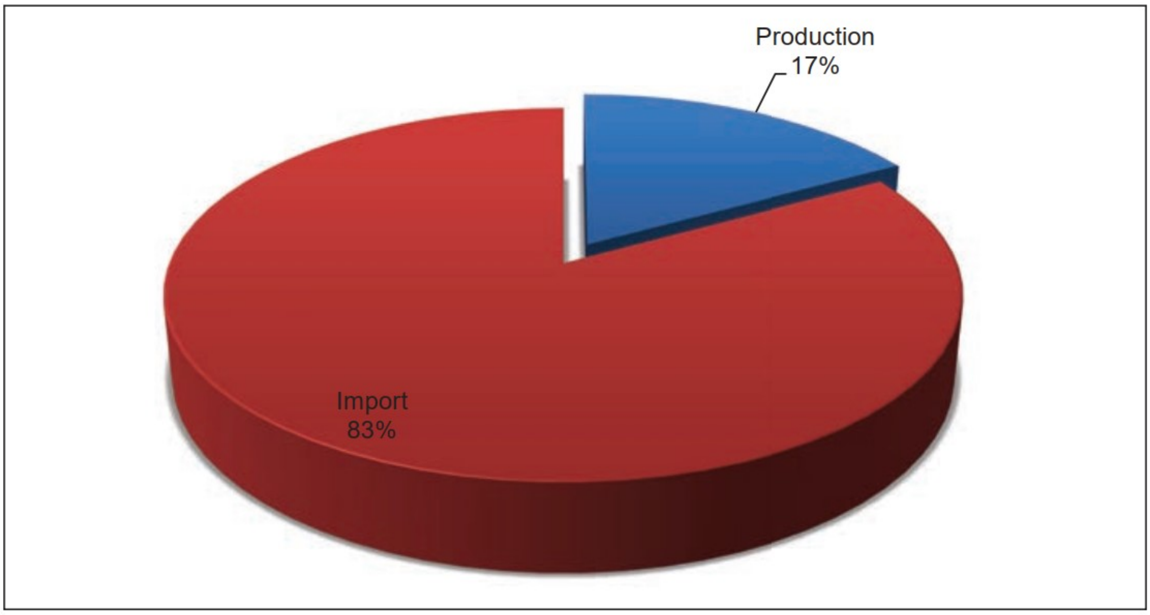


Figure 6: South Africa crude oil primary in 2015 (source [49])

As shown in Figure 6, in 2015, the country was heavily dependent on imported crude oil and the situation is likely to continue if no other alternatives to produce liquid fuels are provided. South Africa imports its liquid fuels from Africa, middle east and America with African countries occupying a big percentage (57%, Figure 7) as of 2015.

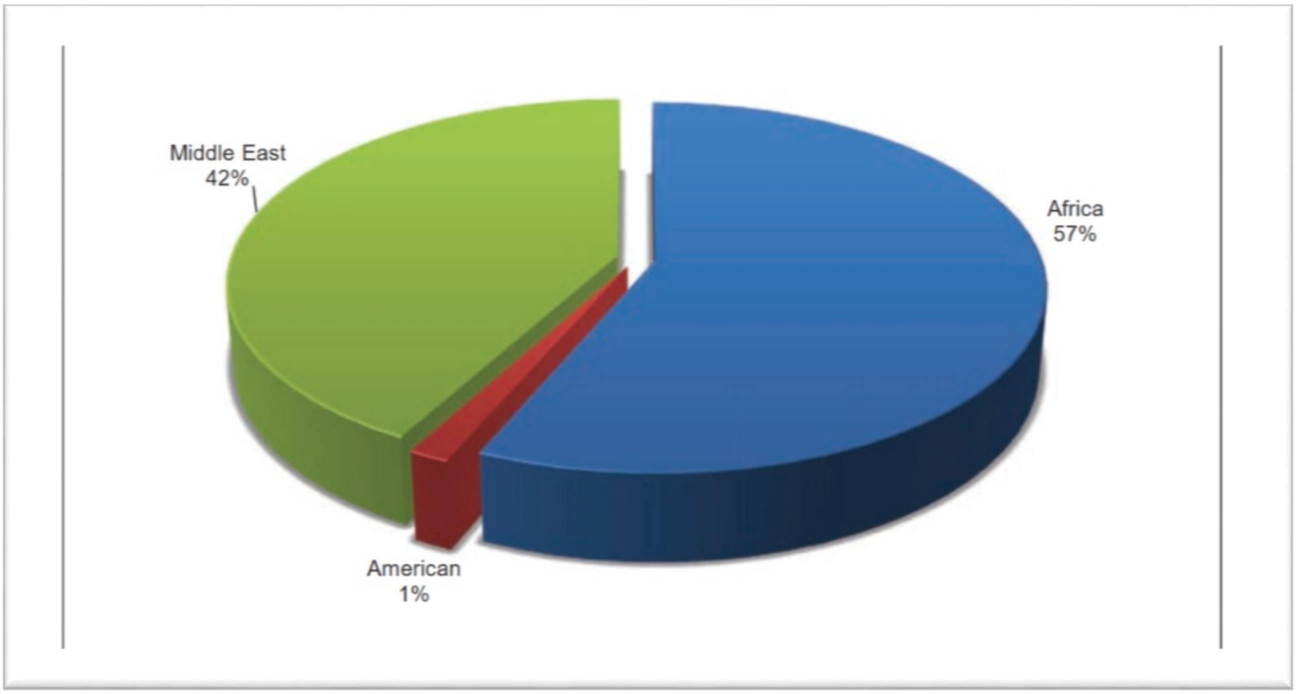


Figure 7: South Africa crude oil imports by region in 2015(Source [49])

The economy based on coal extracted from South Africa in 2006 is the highest GHG emitter country in the continent and in the world, whether the emissions is measured per capita or per energy intensity (one unit of energy used to produce one unit of GHG) as depicted in Figures 8 and 9.

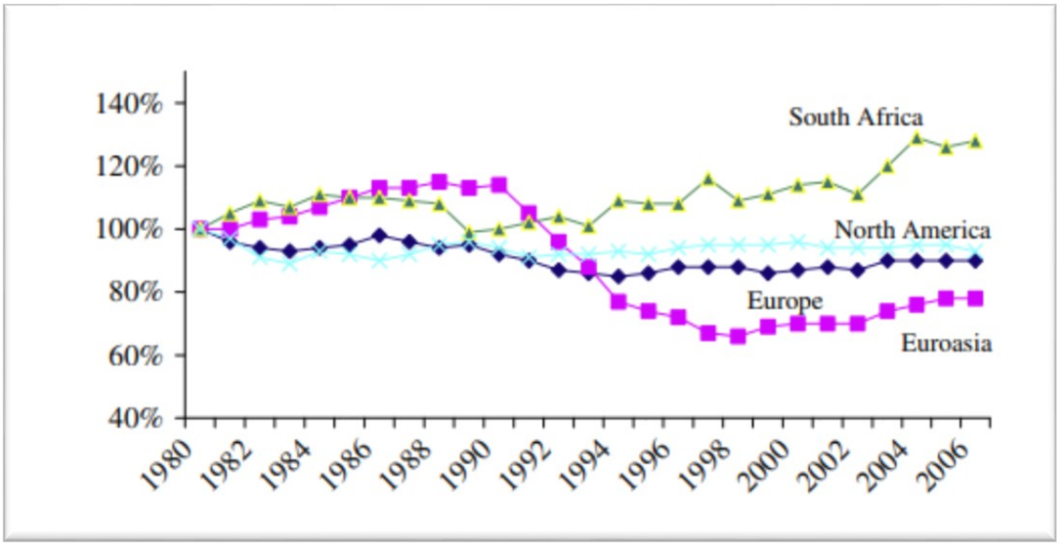


Figure 8: CO_2 emission per capita from 1980-2006(Source [49])

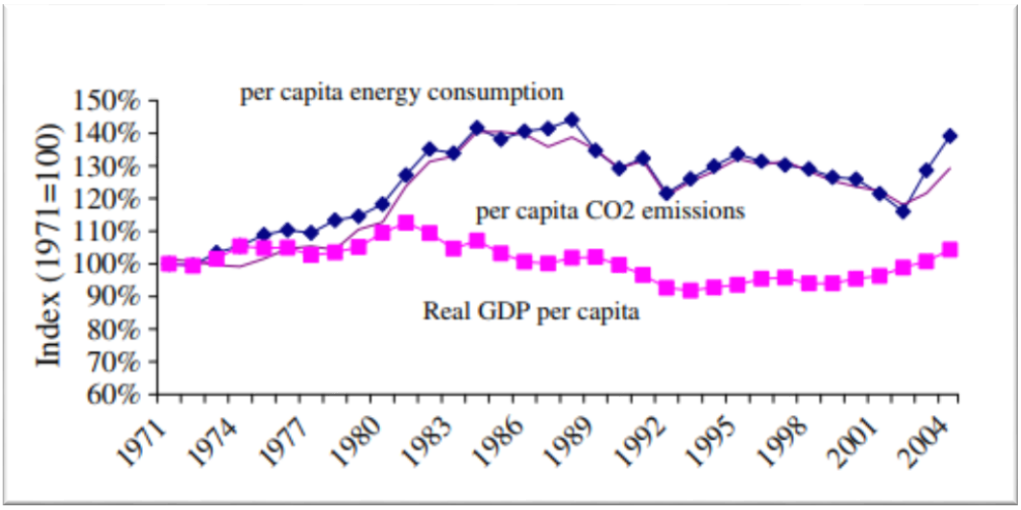


Figure 9: Trend of variables (1971-100)Source [49].

2.3.3 Why advanced biofuels in South Africa?

South Africa is the richest country among other African countries. Environmental, social and economic development of South Africa that based on coal poses a high risk, not only to South Africa itself, but also to other countries in the continent as well as the whole world in general. This is due to the amount of GHG emissions emanating from burning of coal. Once South Africa develops and accepts advanced biofuels technology, technology transfer with other African countries will be easy. The following points are essential for South Africa to consider advanced biofuels among other alternatives:

I. Like most African countries, South Africa is not an energy secured country. It imports crude oil to satisfy domestic consumption mostly in its transport sector

II. Despite South Africa's many policies for promoting first generation biofuels, investors are still not convinced for investing in this sector mostly because of fear involving debate on energy versus fuel. Only small producers are in the sector and they don't target to produce fuel for being used in the transport sector [40].

III. Boosting the agricultural sector by helping farmers to gain a bonus from their crop residues which otherwise are considered as waste for rural farmers

IV. Waste management: municipal solid waste will be handled easily

V. Feeding animals: left overs (cake) a byproduct which remain after extracting fuel is very rich in nutrients which is a good fodder for animals

VI. Pollution reduction: renewable fuel will be generated which will substitute petroleum products in transport sector

VII. Job creation: the sector has job creation potential compared with jobs obtained in the refinery of crude oil. It was estimated in Thailand that ethanol production generates 17-20 times more jobs than petrol and 90 % jobs was concentrated in agriculture sector [40].

VIII. The technology will not compete with food as opposed to first generation one and 14% of land is underutilized hence growing energy crops will not have direct impact on food crops, also marginal land can be used.

IX. South Africa has a well-known rich history in R&D for technologies regarding the conversion of cellulosic biomass which started in 1970s when Council for Industrial and Scientific Research (CISR) began funding a study program to develop a technically and commercially viable process to convert bagasse into ethanol [40].

X. Energy diversification: Convention fuel reserves are predicted to be depleted soon, so by introducing new technology of generating fuel will help to avoid depletion surprise.

XI. South Africa has clear policy regarding biofuels, it was developed by biofuel task team and ratified by the government in 2007 where the blending mandate was put on 2% with petroleum product. The policy has been revised in 2012 and allowed 5% blending of biodiesel with diesel and 2% to 10 % blending of ethanol with petrol [40].

2.3.4. Source of advanced biomass feedstock in South Africa

Advanced biofuel feedstocks also known as lignocellulosic feedstock include: crop residues, forest wastes, municipal solid wastes, energy crops (woody and herbaceous). The following major crops are grown in SA as presented in [50] which have potential for generating many residues as advanced biofuel feed stock.

2.3.4.1 Grain crops

2.3.4.1.1. Maize

Maize is the most important crop grown in SADC region. Maize contains most important carbohydrates and it is the food for both human and animals. South Africa is the leading producer of maize in the region. Generally, maize production in SA ranges between 12 million tons to 14 million tons per annum [50]. It is grown mainly in North West, The Free State and Mpumalanga. Two types of maize are grown in SA: white for human consumption and yellow for animal consumption. The planting season for maize in SA starts during late spring/early summer. SA is a net exporter of maize. The residues generated when harvesting and processing maize are: stalks, cobs, leaves and husks [50, 51].

2.3.4.1.2. Wheat

The second most important grain crop, after maize, produced in SA is Wheat. It is a very important crop because it plays a big role in the national food security. It is used mainly for producing bread, biscuits, breakfast cereals, and rusk for human consumption and the rest is used as animal feed. Wheat is also used for non-food uses such as adhesives and industrial uses as starch on coatings. South Africa is an importer of wheat. The planting season is between April and June in the Western Cape and between May and end July in Eastern Free State province. In SA, the wheat marketing season starts early in the October and ends with September of the following year. Residues generated during harvesting and processing of wheat are called straw [50, 51].

2.3.4.1.3 Barley

Barley is the third important grain in SA after maize and wheat. Production of malting barley in SA is concentrated in the dry land of Southern Cape which receives precipitation of at least

350mm because it is not economical for other areas where precipitation falls below 350mm. The concentration of malting barley in Southern Cape has associated advantages like easy transportation and facilitating storage, control, extension and research which otherwise implies a high costing factor. Other areas where barley is found in small quantity are North West, Limpopo and Free State. The growing season of malting barley in SA is April to October. The use of barley is in the production of malt for brewing beers, animal feed and pearl barley [50].

2.3.4.1.4 Sorghum

Sorghum is an African indigenous crop. There exist two types of sorghum: sweet and bitter but sweet cultivars are the most preferred type. Sorghum does not require a lot of rainfall to grow which makes it a good candidate for arid and semi-arid climate like that of SA. It is grown in Northern Cape, Western Free State, Mpumalanga, the drier parts of North West and Limpopo provinces. The planting period of sorghum in SA is between mid-October and mid-December. About 60 thousand hectares was projected for growing sorghum in SA in 2017/2018. The national consumption is around 200 thousand tons per annum[50]. SA is a net importer of sorghum. Sorghum Stover is the name of residue after the grain has been removed.

2.3.4.1.5. Dry Beans

Dry beans in SA is preferred because of its high-water-use efficiency and its contribution to soil quality by fixation of nitrogen in the soil [50]. It is a feedstuff for animals and plays a major role in food security as it contains much protein. It is grown mainly in the Free State, KwaZulu-Natal, Limpopo, North West and Northern Cape provinces. South Africa is a net importer of dry beans [50].

2.3.4.2 Oil seeds

2.3.4.2.1 Groundnuts

In SA, groundnuts are grown mainly in the Free State, North West and Northern Cape. It is also grown in Limpopo, Mpumalanga and KwaZulu-Natal in small quantities. The planting period is mid-October to mid-November. The marketing season starts in March and ends in February of the following year. Groundnuts are rich in protein. Groundnuts can be used mainly to produce oil for cooking and making peanuts butter [50].

2.3.4.2.2 Sunflower seed

It is produced mainly in Free State and North West provinces. Limpopo. Mpumalanga and Gauteng provinces also grow sunflower seed but they come after the above-mentioned provinces. SA is ranked as the 10th largest producer of sunflower seed in the world. The growing period for sunflower seed is from November to December in Eastern parts and up to middle January in the Western part. Sunflower performs well under dry conditions compared to other crops and it is planted in marginal areas in SA. The oil produced from sunflower are used for cooking. The oilcake as a byproduct can be used as animal feed. In 2017 the global contribution of SA in sunflower was 850 thousand tons in 46.1 million tons [50]. SA remains to be a net importer of sunflower seed.

2.3.4.2.3 Macadamia nuts

In SA, 180 hectares (ha) is reserved for macadamia production with 80 ha harvested for export. Department of Agriculture, Forest and Fisheries (DAFF) together with Eastern Cape Department of Rural Development and Agrarian Reform as a private-public partnership support the crop. It has created 110 permanent jobs [50]. There is a plan to expand the development of macadamia in Eastern Cape, KwaZulu-Natal, Mpumalanga and Limpopo provinces.

2.3.4.2.4 Soya beans

Soya beans are grown in Mpumalanga, the Free State and KwaZulu-Natal in large quantities. It is also available in Limpopo, Gauteng and North West in lower quantities. It is a difficult crop to grow and not all areas are suited for it. Soya beans contain enough protein and its used to produce milk for under-nourished children. In 2017, soya beans were planted on 574 hectares

[50]. The projection shows that 900 hectares will be required which will give 2.1 million tons in 2026. The growing period of soya beans in SA is November to December. The by-product of soya beans (oilcake) is a good candidate for advanced biofuels.

2.3.4.2.5 Canola

Canola is an oil seed introduced which was developed in the early 1970s using traditional plant breeding techniques by Canadian plant breeders. The canola seeds have very low level of saturated fat. About 99% of the canola crop in SA is concentrated in Western Cape province, especially in the Southern Cape.

2.3.4.2.6 Sugar cane

Sugar cane in South Africa is grown predominantly in KwaZulu-Natal. It is also found in Mpumalanga and Eastern Cape. The sector comprises 29 000 registered sugarcane growers [50]. Sugar cane is ratoon crop and after it is grown it gives up to 10 new cane stalks before it can be replaced. SA sugar industry is ranked among first 15 in the world. In SA there exist 14 sugar mills located nearly where cane is grown because after harvesting the cane, sugar can deteriorate only after 3 days. This makes sugar cane to create jobs in deep rural areas on estimate of 79 000 direct jobs which represent 11% of total agricultural workforce in South Africa. The residues from cane farming fields are mainly tops and leaves while the one from mills are bagasse and molasses.

2.3.4.3. Deciduous fruit

This industry in SA comprises with fresh, dried and canned fruit for local consumption and export. Deciduous fruits grown in South Africa include apples, pears, apricots, peaches and nectarines, plums and sloes, grapes, figs and cherries. Deciduous fruits are found largely in Western Cape, however for past 2 decades, the Northern Cape and Eastern Cape provinces[50].

2.3.4.4. Vegetables

Vegetables in SA constitute what is called perishable export industry and comprises with:

tomatoes, onions and cabbages. Vegetables are produced countrywide in SA. Sometimes potatoes are considered as vegetables but not constituent of perishable industry. Potatoes are produced in 16 distinct potato-production regions in SA spread throughout the country. The main regions where potatoes predominate are situated in the Free State, Western Cape, Limpopo and Mpumalanga.

4. 4. Lignocellulosic Biomass Properties and Available Technologies

4.4.1 Properties

Plant biomass is composed by three important elements: cellulose, hemicellulose and lignin as shown in Figure 10. These are the main elements found in plant, also plant biomass constitutes other elements like protein, pectin, non -structural material as sugars and inorganic minerals [52].

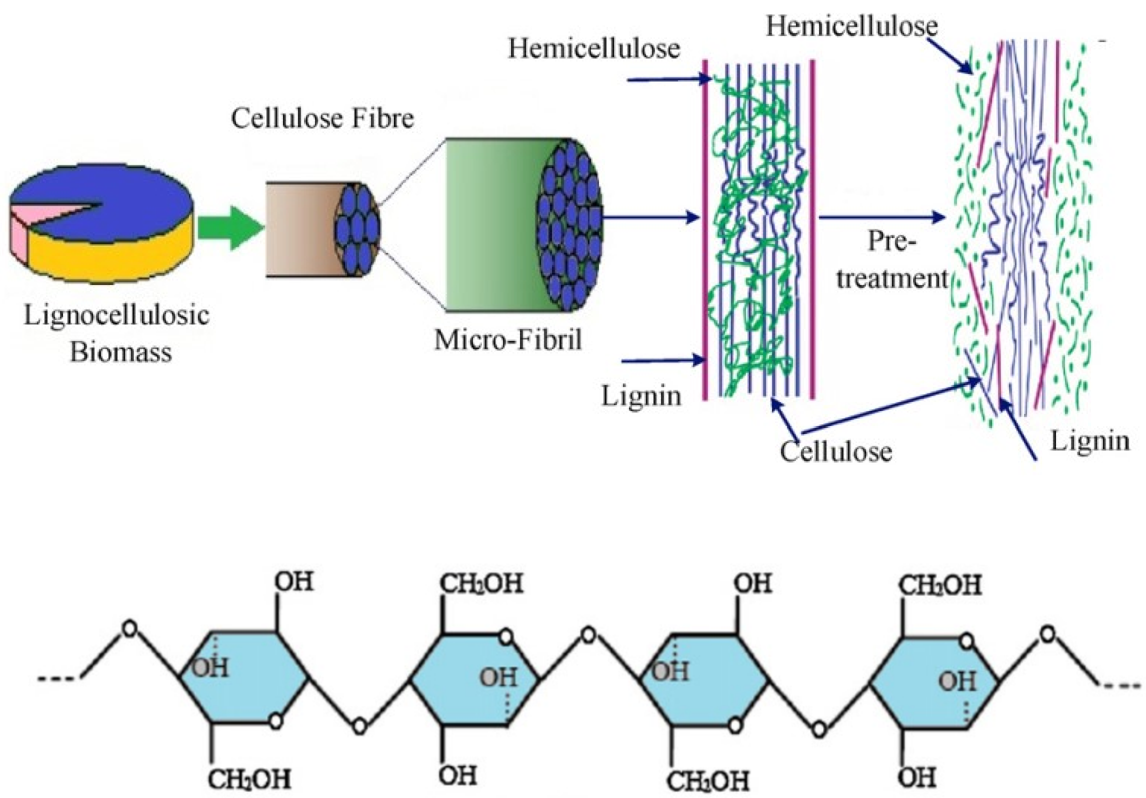


Figure 10: Lignocellulosic plant biomass and cellulose chain(Source: Adapted from [52])

Different plants have different amount of cellulose, hemicellulose and lignin. Table 4 presents some common agricultural biomass and their proportion in lignin, cellulose and hemicellulose.

Table 4: Cellulose, hemicellulose and lignin in selected agriculture wastes. (Source:[52])

Lignocellulosic biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Corn cobs	45	35	15
Cotton seed hairs	80-95	5-20	0
Grasses	25-40	35-50	10-30
Hard wood stems	40-55	24-40	18-25
Leaves	15-20	80-85	0
Newspaper	40-55	25-40	18-30
Nut shells	25-30	25-30	30-40
Paper	85-99	0	0-15
Softwood stems	45-50	25-35	25-35
Solid cattle manure	1.6-4.7	1.4-3.3	2.7-5.7
Sorted refuse	60	20	20
Waste papers from chemical	60-70	10-20	5-10
pulp	30,39.2,35.1	50,26.1,25.6	15,21.1
Wheat straw	37.5	30.0	10.3,8.4
Maize Stover	44.3,38.9	33.5	20.4
Rice straw	34.4,38.3	29.3	19.2
Rice husks	45.0	20.0	30.0
Sugarcane bagasse			

4.4.2 Pretreatment methods for lignocellulosic biomass

Pretreatment of biomass is necessary to be able to convert lignocellulosic biomass into appreciable amount of sugars for subsequent conversion processes. Different methods exist depending on which is appropriate for certain conversion.

Table 5: Types of pre-treatment for lignocellulosic biomass (Adapted from[52, 53]).

Group	Method/Process	Types	Possible change in biomass and notable remarks
Mechanical/Physical	Grinding/milling	“Hammer milling, Ball milling, Two-roll milling, Colloid milling Electroporation, (Vibro milling)”	“Due to size reduction accessible surface area and pore size increases. Thus, decreases cellulose crystallinity Lignin cannot be removed. Most of the methods require high energy. No chemical requirement
	Irradiation	“Gamma ray, Electron beam Microwave”	Leads to cleavage of β-1, 4-glucan bonds and gives a larger surface area and a lower crystallinity. The cellulose component of the lignocellulose materials can be degraded to fragile fibers and lower molecular weight oligosaccharides and cellobiose. This method is too expensive.
	Others	“Hydrothermal, High pressure streaming Expansion, Extrusion, Pyrolysis”	Cellulose rapidly decomposes to gaseous products and residual char when biomass is treated at temperatures greater than 300^{o} C”
Chemical and physiochemical	Alkali.	“Sodium hydroxide, Potassium hydroxide Calcium hydroxide, Magnesium hydroxide Ammonia, Ammonium sulphate”.	“Efficacy order of alkali (NaOH >KOH >$Mg(OH)_2$ and $Ca(OH)_2$) Increase in accessible area, partial or nearly complete delignification; Decrease in cellulose crystallinity; Decrease in degree of polymerization; Partial or complete hydrolysis of hemicellulose. These methods are the most effective and promising processes for industrial applications and usually have rapid treatment rate and need harsh conditions”
	Acid	“Sulphuric acid; Hydrochloric acid Phosphoric acid”	
	Gas	“Choline dioxide; Nitrogen dioxide Sulphur dioxide”	
	Explosion	“Steam explosion, Ammonia fiber explosion, CO_2 explosion, SO_2 explosion”	
	Oxidizing agents	“Hydrogen peroxide; Wet oxidation Ozonolysis”	
	Solvent extraction of lignin	“Ethanol-water, Benzene-Water, Butanol-water, Ethylene glycol, Swelling agents”	
Biological	Fungi and actinomycetes		“Delignification and reduction in degree of polymerization of cellulose and partial hydrolysis of hemicellulose. Low energy requirements and mild environmental conditions are the main advantages. However, the pretreatment rate is very low”.

4.4.3 Conversion technologies for advanced biofuels

There are two main routes to produce biofuels from lignocellulosic biomass: Thermo-chemical, also known as biomass to liquid (BTL) and biochemical[54] . Biochemical is when enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstock to sugars prior to their fermentation to ethanol; while Thermo-chemical also known as biomass-to-liquids, BTL), is where pyrolysis/gasification technologies produce a synthesis gas (CO + H2) from which a wide range of long carbon chain biofuels, such as synthetic diesel, aviation fuel, or ethanol, can be reformed, based on the Fischer–Tropsch conversion" [20].

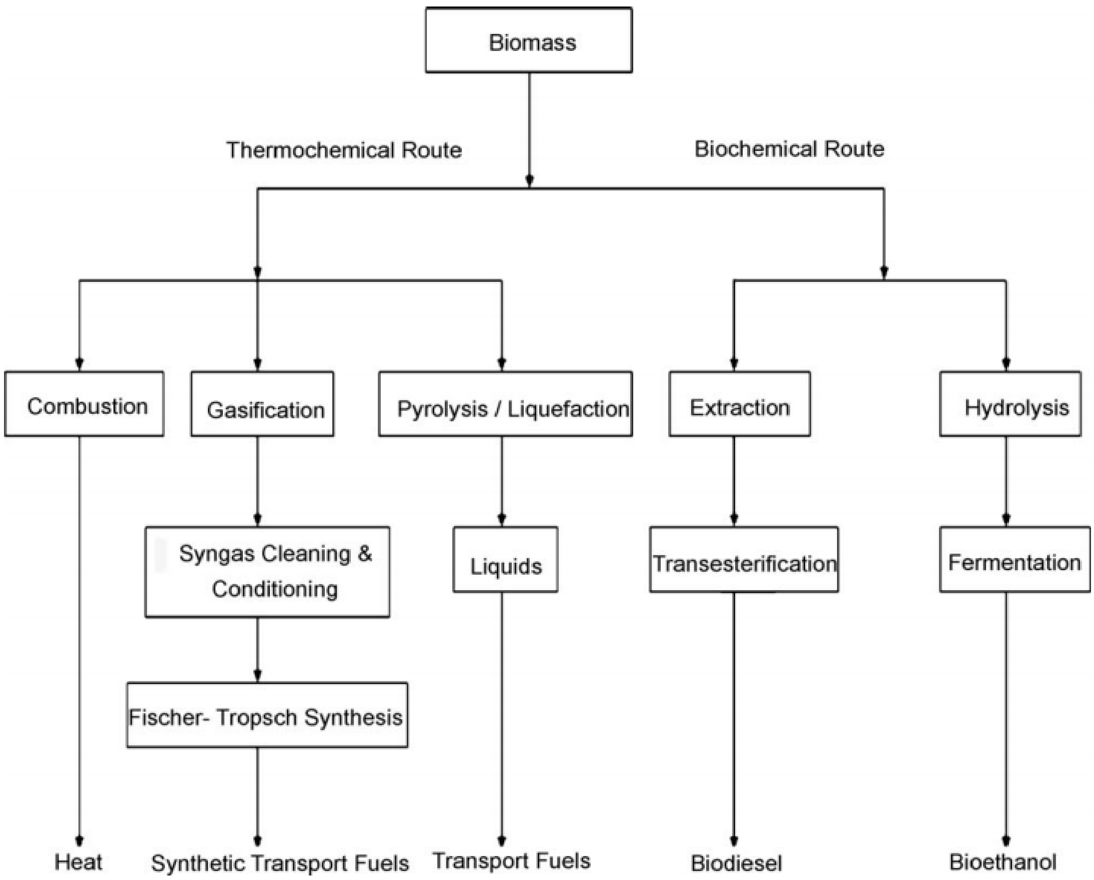


Figure 11:Thermochemical and biochemical biomass conversion technologies[54].

Different feedstock requires different conversion technologies in order to produce a certain type of biofuel (e.g. bioethanol).

Table 6: Technologies used to produce ethanol and practical case examples [22].

Feedstock	**Technology**	**Company, location**
"Corn Stover, wheat straw, milo stubble, switch grass"	"Enzymatic hydrolysis, fermentation, thermochemical"	"Abengoa, Madrid"
"Wood, citrus waste, urban green waste"	"Thermochemical, gasification, fermentation"	"ALICO, Florida"
"Urban green waste, wood chips, car tires, plastics"	"Thermochemical, gasification, fermentation"	"Bioengineering resources, Arkansas"
"Wood construction waste"	"Enzymatic hydrolysis, fermentation"	"Bioethanol Japan, Osaka"
"Hay, grass, manure fibers, straw, paper"	"Enzymatic hydrolysis, fermentation"	"Biogasol, Lyngby"
"Urban trash, rice, and wheat straw"	"Concentrated acid hydrolysis, fermentation"	"BlueFire Ethanol, Irvine"
"Corn Stover"	"Enzymatic hydrolysis, fermentation"	"China Resources Alcohol Corporation, ZhaoDong City "
"Cellulosic biomass	"Gasification"	"CHOREN"
Sugarcane bagasse"	"Thermochemical, gasification, modified Fisher-Tropsch"	"ClearFuels Technology, Hawaii"
"Waste rice straw, rice husks"	"Enzymatic hydrolysis, fermentation (*Klebsiella oxytoca and E. coli*)"	"Colusa Biomass Energy, California"
"Spent pulping liquor"	"Alcohol sulfite cooking liquor to fractionate softwood chips, fermentation"	"Flambeau River Bio-refinery, Wisconsin"
"Wheat straw, barley straw, corn Stover, switch grass, rice straw "	"Enzymatic hydrolysis, fermentation (*Trichoderma reesei*)"	"Iogen , Ottawa"
"Wood chips, corn Stover, switch grass"	"Enzymatic hydrolysis, fermentation"	"Lignol Innovations, Burnaby"
"Switchgrass, wood"	"Enzymatic hydrolysis, fermentation, (*Thermoanaerobacterium saccharolyticum*)"	"Mascoma, Cambridge, Massachusetts"
"Corn fiber, corn cobs Wood and vegetative wastes"	"Enzymatic hydrolysis, fermentation Thermochemical"	"Poet/Dupont, Delaware RangeFuels"
"Paper"	"Gasification"	"UPM, Finland"
"Sugarcane bagasse, wood"	"Enzymatic hydrolysis, fermentation"	"Verenium, Cambridge, Massachusetts"

CHAPTER THREE: METHODOLOGY

3.0 Introduction

Techniques, which have been used to be able to succeed in the present study, are described below.

3.1 Determining potential availability of crop residues and biofuel production

To characterize crop residues available for biofuel production in South Africa, crop production and harvested area have been taken into account. The protocol used to assess the availability of crop residues for biofuel production is shown in Figure 12.

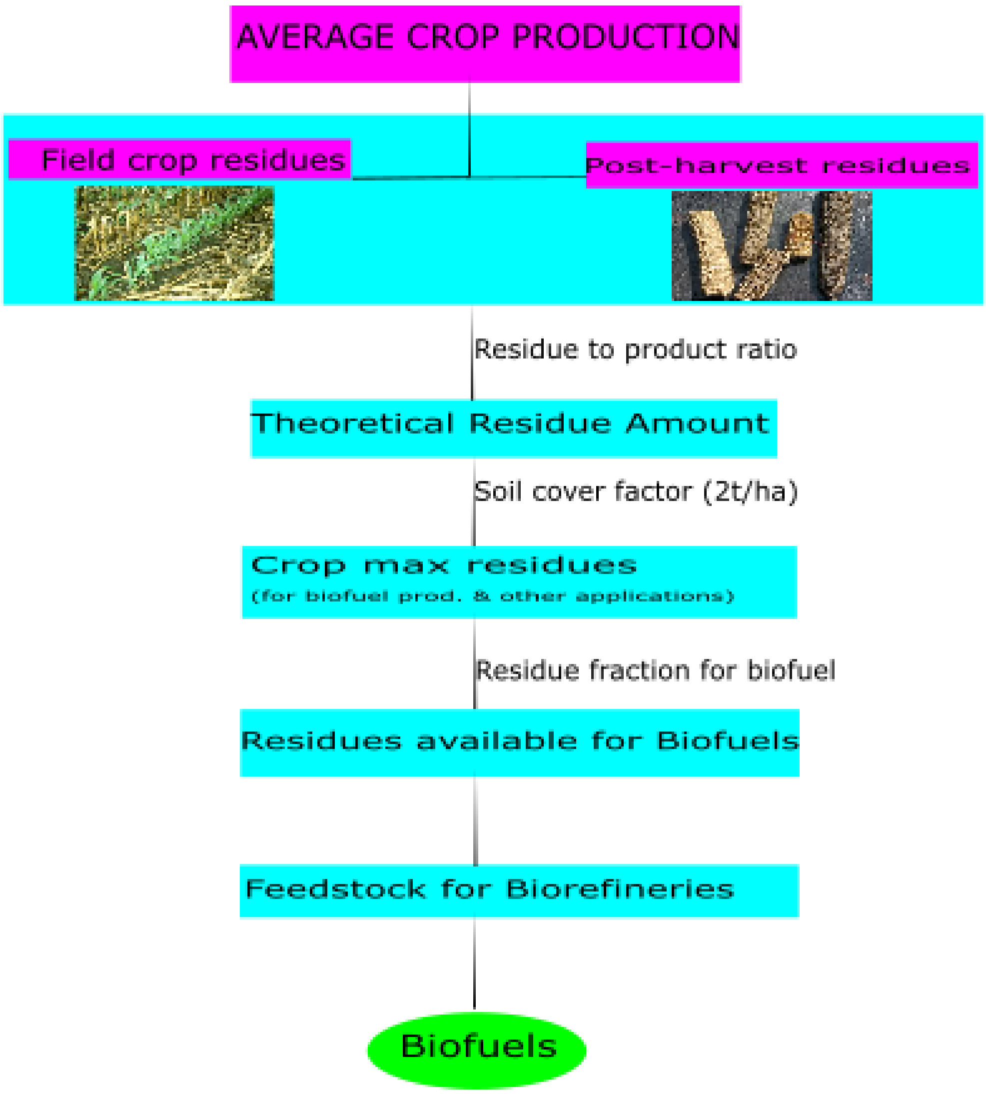


Figure 12: Protocol for biofuel residue assessment

To ensure data quality, average production for a 10-year consecutive period (2008-2017) was chosen as our study time frame Empirical literatures[55, 56] provided the following relations (**Equations 1-20**) which was useful in generating SA data crop residues .

$$\boldsymbol{A_{TR} = A_C * RPR} \qquad \text{Equation (1)}$$

$\boldsymbol{A_{TR}}$, Residue annual total amount in tonnes

$\boldsymbol{A_C}$, Crop annual amount in tonnes

$\boldsymbol{RPR}$, Residue Product Ration

In order to avoid indirect land use change (iLUC) it is essential to left some crop residues in the field for land covering purposes so that organic content in the soil is maintained. The quantity of residues, which can be left in the field, depends on the type of the crop, but an estimate of two to four tonnes per hectare is usually made. Therefore, the maximum amount available residue for producing biofuels can be calculated as:

$$\boldsymbol{A_{MB} = A_{TR} - S * F_C} \qquad \text{Equation (2)}$$

$\boldsymbol{A_{MB}}$, Biomass maximum annual amount for biofuel production in tons

$\boldsymbol{S}$, Harvested area in ha

$\boldsymbol{F_C}$, Field cover factor in t/ha

Bearing in mind that some losses occur during crop residue handling and transportation from the field to production plant, also other uses of crop residues like bedding, animal feeding and other usage [57] have been taken into account in order to avoid indirect conflict which can rise when all residues are used to generate biofuels. Hence, we assumed that only a fraction from maximum available residue can be used to produce biofuel in a sustainable way as illustrated in the following relation (3).

$$\mathbf{A_{CB} = f_{CB} A_{MB}} \qquad \text{Equation (3)}$$

$\mathbf{A_{CB}}$, Collectable biomass total amount as feedstock for biorefineries in tonnes

$\mathbf{f_{CB}}$, Fraction of collectable biomass

3.2 Determining Biofuel Blends

As the production industry of biofuel is supported most of the time by governmental policies, using blending mandate for biofuel to be commercially viable, a blending relation and its subsequent consequence on the environment has been calculated using the following relations from.

$$\mathbf{F_{blend}} = \frac{\mathbf{F_{bifuel}}}{\mathbf{x}} \qquad \text{Equation (4)}$$

$\mathbf{F_{bifuel}}$, Biofuel available quantity

Petroleum fuels and renewable fuels (biofuel) have different energy content. To make comparison between biofuel and petroleum easier and to determine the amount of fossil fuel, which can be saved once biofuel, is used, it is necessary to define a conversion factor (R), which is the ratio between specific energy of biofuel to fossil fuel.

$$\mathbf{F_{Saving}} = \mathbf{R} * \mathbf{F_{biofuel}} \qquad \text{Equation (5)}$$

The equivalence in fossil fuel to the blended one is given by:

$$\mathbf{F_{equivalent}} = \underbrace{\mathbf{F_{saving}}}_{\text{The amount of fossil fuel equivalents to biofuel contained in the blend}} + \underbrace{(\mathbf{1}-\mathbf{x})\mathbf{F_{blend}}}_{\text{The amount of fossil fuel contained in the blend}} \qquad (6)$$

3.3 Life cycle Analysis

Life cycle analysis is an essential parameter in climate change mitigation. In order to calculate the GHG emissions reduction or increase, a well-to-wheel analysis technique which is the calculation of emitted GHG from raw material extraction, processing, transportation to the plant, the processing and refining of the fuel, to the distribution and combustion of the fuel in its end use. GHG emissions reduction, Reduction in SCC, Carbon dioxide social cost, and Well – to-wheel GHG emissions factors were calculated using the following equations.

$$\Delta_{\mathbf{GHG}} = \mathbf{C_{fossil}}\mathbf{F_{equivalent}} - \mathbf{C_{blend}}\mathbf{F_{blend}}$$

$$\mathbf{C_{blend}} = \mathbf{x}\mathbf{C_{biofuel}} + (\mathbf{1}-\mathbf{x})\mathbf{C_{fossil}} \qquad \text{Equation (7)}$$

$$\Delta_{GHG}\% = \frac{\Delta_{GHG}}{C_{fossil}F_{equivalent}} * 100$$

$$\Delta_{SCC} = \Delta_{GHG} * SCC$$

$$\Delta_{SCC}\% = \frac{\Delta_{SCC}}{C_{fossil}F_{equivalent}SCC} * 100 = \Delta_{GHG}\% \qquad \text{Equation (8)}$$

Δ_{GHG} **,** GHG emissions reduction (t CO_2 eq)

Δ_{SCC} , Reduction in SCC ($)

SCC , Carbon dioxide social cost ($ t^{-1} CO_2)

$C_{biofuel}$, Well – to-wheel GHG emissions factors of biofuel

C_{fossil} , Fossil fuels (t CO2 eq l^{-1} fuel)

C_{blend}, Blended fuels (t CO2 eq l^{-1} fuel)

Well to Wheel GHG emissions ($C_{biofuel}$ and C_{fossil}) and other characteristics of advanced or cellulosic ethanol like ethanol specific energy, density, etc has to be stated in order to be able to make conversion or comparison between conventional and non-conventional energy carriers . Those characteristics are tabulated in table 7 below.

Table 7: Well to Wheel GHG emissions and other characteristics of advanced or cellulosic ethanol

Fuel	**Well-to-wheel GHG emissions (g CO2 eq MJ^{-1} fuel)**	**Density (kg l^{-1})**	**Specific energy (MJ kg^{-1} fuel)**	**Well-to-wheel GHG emissions (kg CO2 eq l^{-1} fuel)**	**R (l fossil fuel l^{-1} biofuel)**
Cellulosic Ethanol	25.73	0.789	29.70	0.60	0.68
Gasoline	86.80	0.740	46.50	2.99	-

3.4 Sensitivity analysis and logistics

The change in the production rate of crops , harvested area and the field cover factor may affect the availability of crop residues which can impact biofuel production quantity .To determine the impact of production quantity and area harvested on the results , crop yield (t/ha) can be calculated as :

$$\mathbf{Y_C} = \frac{\mathbf{A_C}}{\mathbf{S}}$$ Equation (9)

Equation (2) can be rearranged as follows based on Y_C calculated above

$$\mathbf{Y_{MB}} = \frac{\mathbf{A_{MB}}}{\mathbf{S}} = \mathbf{Y_C(RPR) - F_C}$$ Equation (10)

$\mathbf{Y_{MB}}$, Biomass maximum amount available

$$\mathbf{Y_{CB}} = \frac{\mathbf{A_{CB}}}{\mathbf{S}} = \mathbf{f_{CB}Y_{MB}}$$ Equation (11)

$\mathbf{Y_{CB}}$, Collectable biomass

$$\mathbf{Y_B} = \frac{\mathbf{A_B}}{\mathbf{S}} = \mathbf{Y(Y_{CB})}$$ Equation (12)

$\mathbf{Y_B}$, Biofuel yield per area harvested

3.4.1 Effect of field cover factor

In order to consider a crop for biofuel production, the biomass maximum amount available from it must be greater than zero as expressed by the following equation.

$$\mathbf{Y_{MB} > 0 \longrightarrow Y_C(RPR) > F_C \longrightarrow (F_C)max = Y_C(RPR)}$$ Equation

3.4.2 Effect of crop yield

Any change in crop yield has signficant effect on biofuel production because the area harvested or crop quantity has to be considered for certain quantity of desired biofuel. For a very defined field cover factor, , the biomass maximum amount available must greater or equal to zero for a treshold crop yield as shown by the following eqation

$$\mathbf{(Y_C)min} = \frac{\mathbf{F_C}}{\mathbf{RPR}}$$ Equation (14)

3.4.3 Logistics of collecting and transporting residues

To collect residues from the field to the plants involves many aspects which affects the prduction cost. The collection area around the plant is given by equation 15. The radius of the circle of which area has been calcualted by the eqation 15 is given by equation 16 in mile.

Assuming a tortoisefactor (1.27) as the road follow non linear path from the field to the plant , the farthest distance was given by equation 17 . The average distance is 0.66 of the farthest one .

$$.S_C = \frac{F}{(Y_{CB} f_L f_A)} \qquad \text{Equation (15)}$$

F, Biorefinery annual crop residues demand (t/year)

$\mathbf{f_L}$, Fraction of surrounding farmland containing crops

$\mathbf{f_A}$, Fraction of total available farmaland from which residues can be collected

$\mathbf{Y_{CB}}$, Amount of collectable biomass per ha per year

$$\mathbf{R_C = 0.00062\left(\frac{mi}{m}\right)\sqrt{\frac{10^4\left(\frac{m^2}{ha}\right)}{\Pi}S_C} = 0.035\sqrt{S_C}} \qquad \text{Equation (16)}$$

$\mathbf{R_C}$, Collection radius of a circle having area S_C

$$\mathbf{D_F = 1.27(RC) = 0.044\sqrt{S_C}} \qquad \text{Equation (17)}$$

$\mathbf{D_F}$, Farthest distance from point of residue collection to the plant

$$\mathbf{D_A = \frac{2}{3}(D_F) = 0.03\sqrt{S_C}} \qquad \text{Equation(18)}$$

$\mathbf{D_A}$, Average residue transportation distance

Based on the average and farthest distances , the maximum and average cost of transportation is given by equation 19 and 20 respectively

$$\mathbf{(C_T)max = 0.044\gamma\sqrt{\frac{F}{(Y_{CB}f_Lf_A)}}} \qquad \text{Equation (19)}$$

$\mathbf{(C_T)max}$, Maximun transport cost of the residue ($\$^{t-1}$ feedstock)

$$\mathbf{(C_T)av = 0.33\gamma\sqrt{\frac{F}{(Y_{CB}f_Lf_A}}} \qquad \text{Equation (20)}$$

$\mathbf{(C_T)av}$, average transport cost of the residue ($\$t^{-1}$ feedstock

3.5 Methodology for analyzing data

- Excel software was used to analyze data by plotting graphs, generating mean and average on crop production and on area harvested
- Ethanol yield calculator was used to obtain amount of energy which crop residues from South Africa Can generate per year.

CHAPTER FOUR: DATA PRESENTATION, RESULTS AND DISCUSSION

4.0 Introduction

This section contains data findings on crop residues, and gives analysis as well as implications of the results generated.

4.1 Data on Residues

The information on crop residues produced most of the time are not readily available. However, the information on crop production and area harvested is available. To generate data on crop residues, a technique called residue to product ratio has been used. Table 8 shows the calculated theoretical residue value from average crop production in South Africa from 2008 to 2017. The results showed that the highest average crop production in South Africa for the period 2008 to 2017 is sugarcane (~17 Mt) followed by maize with approx. 12 Mt and then Potato (~2 Mt), wheat (~1.7 Mt) respectively in that order. Figs and cherries were the least produced crops in South Africa within the studied period with estimates of 200 and 300 tons respectively. Apples (~0.8 Mt) and soybeans (~0.7 Mt) are also highly produced in South Africa in contrast to rice with low production level at (~3000 t).

South Africa is a county plagued by water scarce and extreme drought most part of the year has an average annual rainfall of about 464 mm which may not support or be suitable for rice production which requires a marshy environment to thrive. The main reason behind the high production of maize in South Africa is that it is the principal food crop for most households. In terms of biofuel production, the South African government has excluded maize from being used as a bioenergy crop to avoid fuel vs. food competition and dilemma. However, its residues can be used to produce advanced biofuels.

Grain crops (maize, wheat, barley, rice and dry beans) contribute more residues than other type of crop. Of the ~43 Mt average residues produced in South Africa, ~32 Mt comes from grain crops followed by sugar cane with an average contribution of ~6 Mt. Next to sugar cane are oil-crops (ground nuts, sunflower seeds, soybeans) and vegetable crops (potato, tomato, cabbages) with ~3Mt and 1Mt respectively. The least contributor in average residue production is deciduous fruits (apples, pears, peaches and nectarines, plums and slows, grapes, figs and cherries) with an estimated 0.8 Mt as also represented in Figure 13.

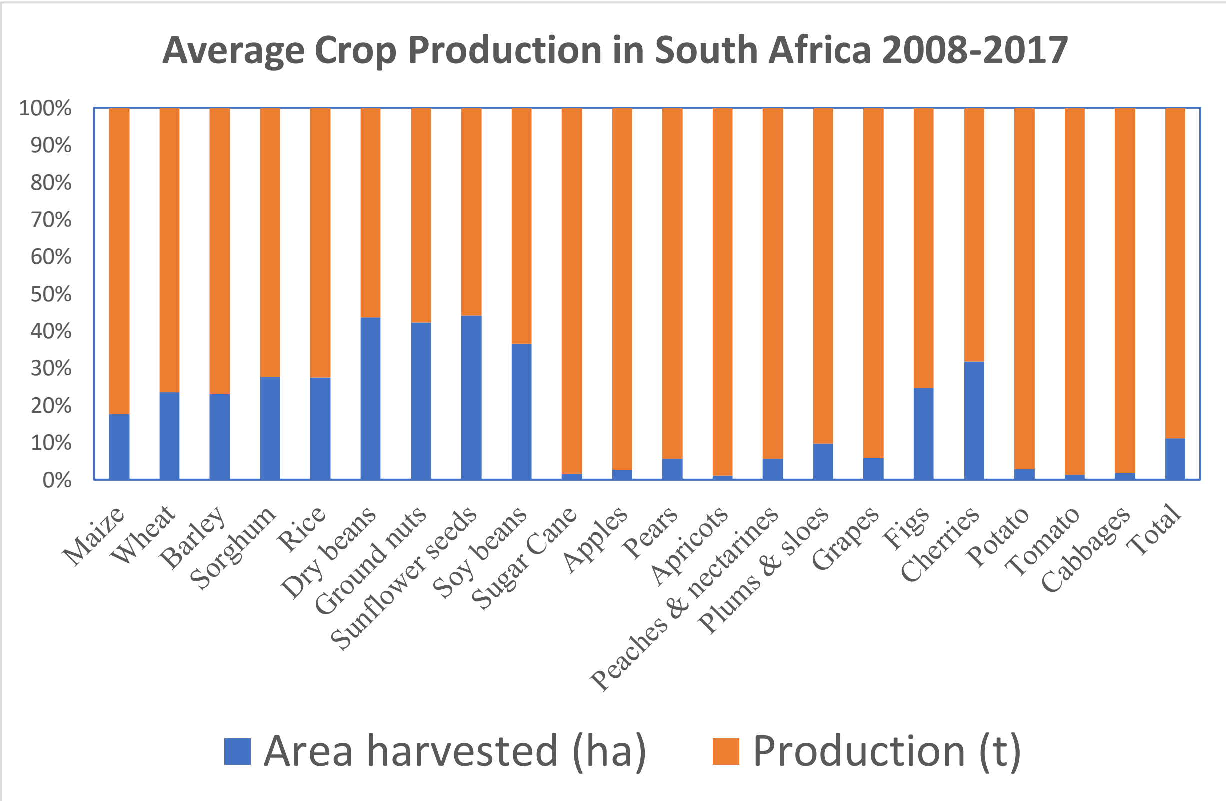


Figure 13: Average crop production in South Africa from 2008 to 2017

Table 8: Generated theoretical residue from average crop production (2008-2017)

Types	Name of crop	Area harvested (ha)	Average crop production (tons)	Residue to product ratio	Theoretical residue generated (tons)	Field cover factor tons /ha	Collectable residue (tons)
Grain crops	Maize	2 573 760.00	12 065975.60	2.30 [58]	27 751 742.00	2	22 604 222.00
	Wheat	552 848.50	1 794 300.00	1.80 [58]	3 229 740.00	2	2 124 043.00
	Barley	83 101.50	277 550.00	1.30 [58]	360 815.00	2	194 612.00
	Sorghum	67 944.50	177 320.00	2.26 [59]	400 743.20	2	264 854.20
	Rice	1 152.20	3 045.20	1.70 [59]	5 176.84	2	2 872.44
	Dry beans	456 170.00	58 762.50	1.70 [59]	98 896.25	2	7 662.25
Oil crops	Ground nuts	50 242.50	68 758.00	2.30 [58]	158 143.40	2	57 658.40
	Sunflower seeds	572 705.00	722 600.00	3.00 [58]	2 167 800.00	2	1 022 390.00
	Soybeans	438 805.00	758 450.00	1.70 [58]	1 289 365.00	2	411 755.00
Sugar crop	Sugarcane	265 414.00	17 311 711.20	0.35 [58]	6 059 098.80	2	5 528 270.80
Deciduous fruits	Apple	22 781.90	835 075.80	0.47 [59]	392 485.62	2	346 921.82
	Pears	22 219.10	374 176.50	0.45 [59]	168 379.42	2	123 941.22

	Apricots	477.80	42 649.30	0.35 [59]	14 927.26	2	13 971.66
	Peaches and nectarines	10 258.30	171 463.70	0.35 [59]	60 012.30	2	39 495.70
	Plum and Sloes	7 628.10	70 351.60	0.35 [59]	24 623.06	2	5 889.34
	Grapes	115 851.40	1 881 453.40	0.07 [59]	122 294.47	2	99 123.67
	Figs	67.11	205.12	0.45 [59]	92.30	2	-41.92
	Cherries	160.60	344.30	0.83 [59]	285.77	2	-35.43
Vegetables	Potato	62 471.30	2 193 202.30	0.25 [60]	548 300.58	2	423 357.97
	Tomato	7 570.00	551 732.30	0.30 [61]	165 519.69	2	150 379.69
	Cabbages	2 288.20	130 616.10	2.30 [61]	326 540.25	2	321 963.85
	Total	**4 903 365.00**	**39 489 742.90**		**43 344 981.20**		**33 743 385.00**

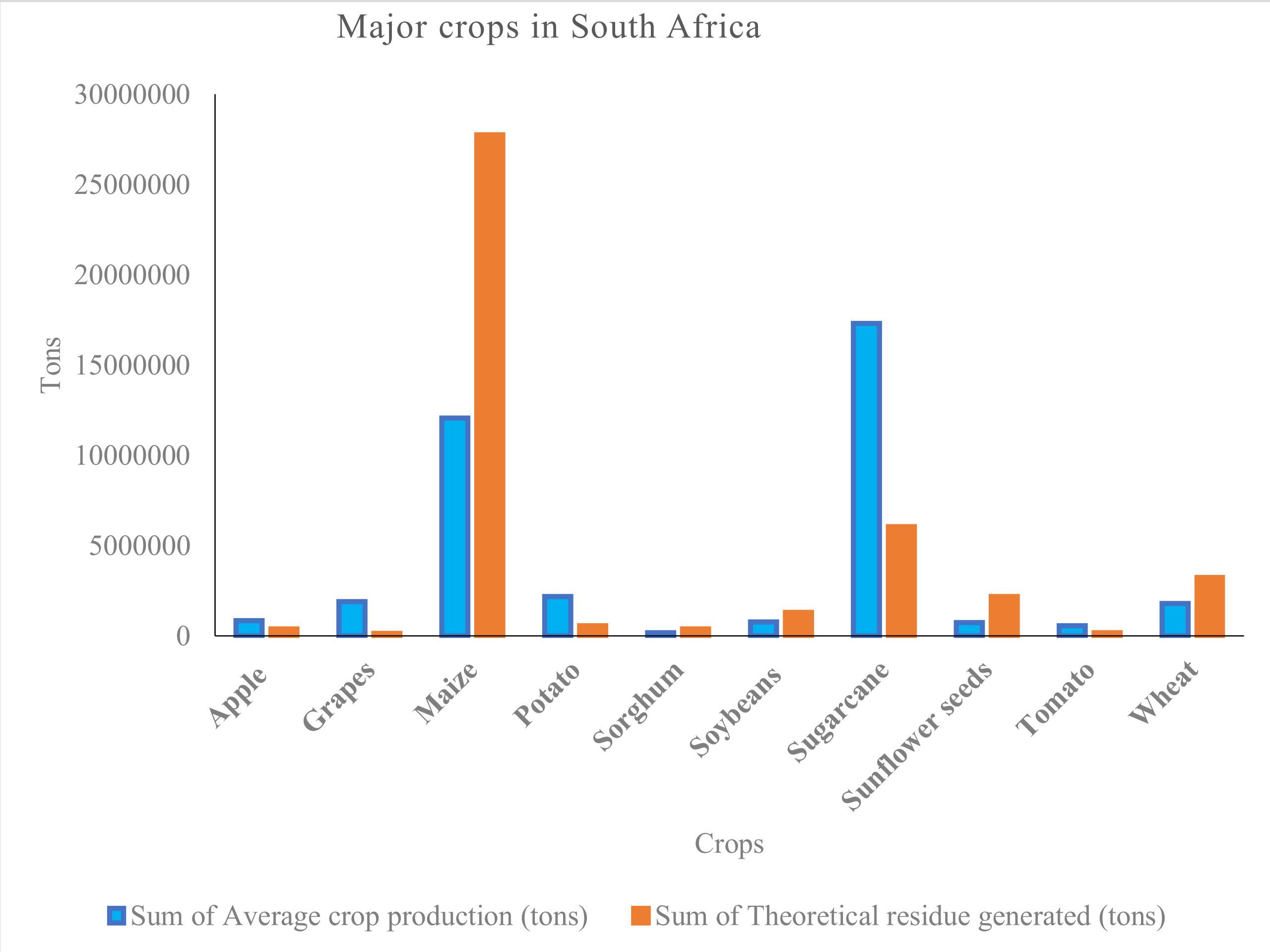


Figure 14: Average production of major crops and their theoretical generated residues

Of the grain crops in South Africa, maize is the major contributor of residues with ~28 Mt out of ~32 Mt due to its importance in South Africa as a major staple food cultivated in large areas[50]. Among the oil crops, sunflower seeds contribute more than groundnut and soybeans with ~2 Mt out of ~3 Mt. Potato is the main contributor of residues among the vegetables with ~0.5 Mt out of ~1Mt.

The highest theoretical residues in South Africa is generated from maize (~28 Mt) followed by sugarcane (~6 Mt)[62, 63]. The 3rd, 4th and 5th theoretical residues generation came from wheat

(~3 Mt), sunflower seeds (~2 Mt) and soybeans (~1 Mt) respectively. The least amounts of residues are generated from figs and cherries with an infinitesimal contribution to the residues in total.

A careful look at the calculated theoretical crop residues highlights the importance of residue to product ratio (RPR). Some crops may produce more residues than others even if they have the same amount of production in tons. For example, sugar cane has a high production amount but its RPR is very small (~0.35) compared to sunflower (~3.0).

Using equation 2 and by setting the field cover factor by 2t/ha the collectable biomass maximum annual amount in tons is **33 743 385** as illustrated in Table 8.

As discussed in equation 3, the all available biomass cannot be used for producing biofuels because beside biofuel production biomass have many other applications, in order to avoid conflict of interest we assumed that only 40% of maximum collectable biomass (33743385 t) can only be used to produce biofuels and it is equals to 13 497 354 tones.

4.2 Estimating potential biofuel production from collectable agriculture residues

According to Ji [62], one ton of crop residues is needed to produce 0.17 to 0.20 t of bio-ethanol. Hence, from ~13.5 Mt of residues calculated from 19 potential crops we can estimate the amount of biofuel which can be generated from those residues. For the analysis, biochemical and fast pyrolysis conversion routes was used in the present study to generate bioethanol and bio-oil as follows:

a) Using biochemical conversion routes, the average value (~0.18 t) of the produced bioethanol range (0.17 to 0.20 t**)** could be used to generate an estimated **~2.5** million tons of bio-ethanol (4.9 Gl) from 13.5 Mt of crop residues per annum.

b) Employing the fast pyrolysis route for bio-oil, two tons of crop residues are needed to generate one ton of bio-oil. Hence, from 13.5 Mt of residues, approximately 7 million tons of oil equivalent could be generated per year

4.3 Life Cycle Analysis

Life cycle analysis is an essential parameter in climate change mitigation. In order to calculate the GHG emissions reduction or increase, a well-to-wheel analysis technique which is the calculation of emitted GHG from raw material extraction, processing, transportation to the plant, the processing and refining of the fuel, to the distribution and combustion of the fuel in its end use, Equations 7 and 8 were inserted in excel and the results are tabulated in the table below.

Table 9: Amount of bioethanol-blended fuels which might be produced from crop residues in South Africa

Blended fuel	$F_{blend\ (Ml)}$	F_{saving} (Ml)	$F_{equivalent\ (Ml)}$	C_{blend} (kg CO_2 eq l^{-1} fuel	Δ_{GHG} Kt CO_2 eq	Δ_{GHG} %
E85	4 517.64	2 796.16	3 473.80	0.95	6 094.92	58.86
E10	38 400	2 796.16	37 356.16	2.75	6 094.91	5.45
E5	76 800	2 796.16	75 756.16	2.87	6 094.91	2.69

To lessen the quantity of CO_2 emitted in atmosphere from fossil fuels, biofuels has to be mixed with non-conventional fuels which is known as blending. The common type of blending from ethanol are E5, E10 and E85.In south Africa, the research shows that crop residues have potential to generate about 4.9Gl of bioethanol per year. The volume of blended bioethanol fuel is presented in the Table 9. Results revealed that E85, E10, E5 can produce 4.56, 38.40

and 76.800 Gl blended fuels respectively in South Africa which can reduce GHG emissions up to 55.86% (Figure 15and 16).

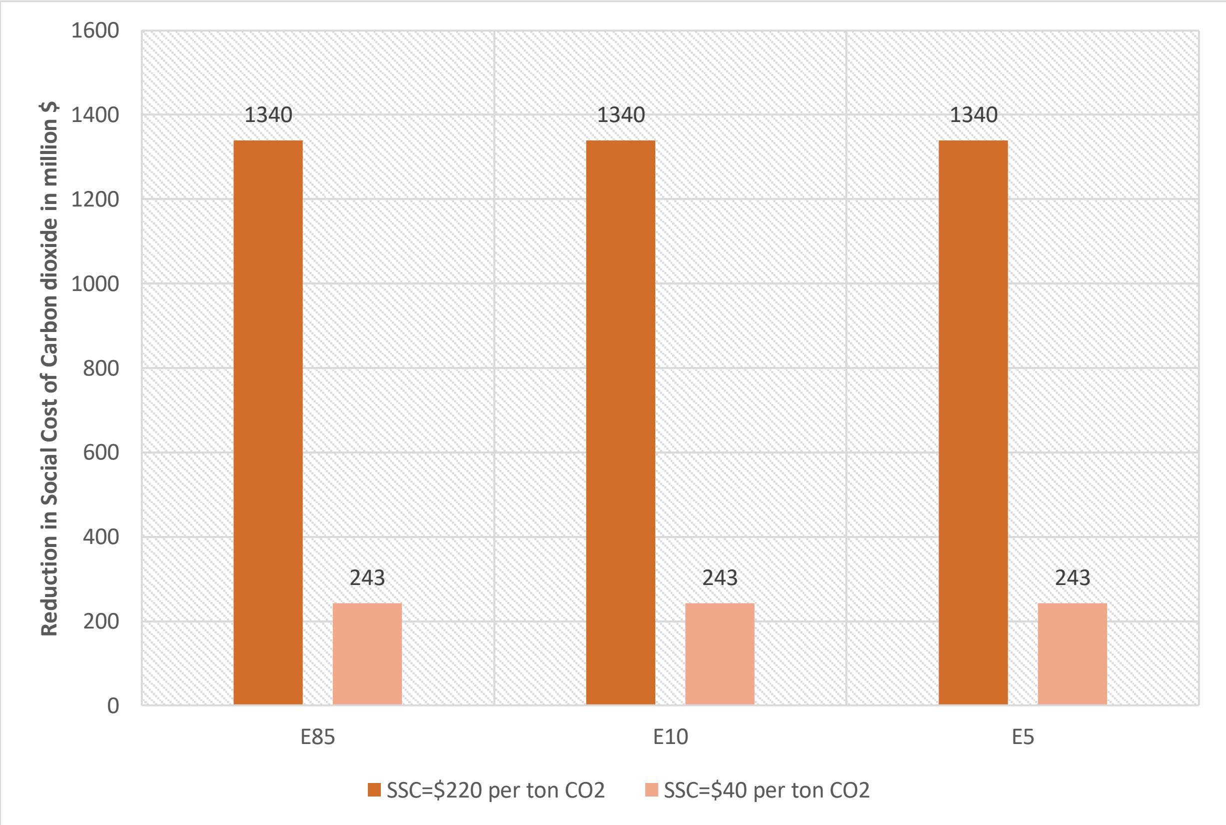


Figure 15: Reduction is social cost of carbon dioxide as a result of using bioethanol blends

From figure 15, it is clear that the total decrease is the same for both blending techniques ~1.3 billion $ considering SSC=$220 per ton of CO2 emitted and 243 million $ when considering SSC= $ 40 per ton of CO2 emitted. The percentage of decrease is not the same as shown by figure 16 and it is higher for E85 compared to other blending technics.

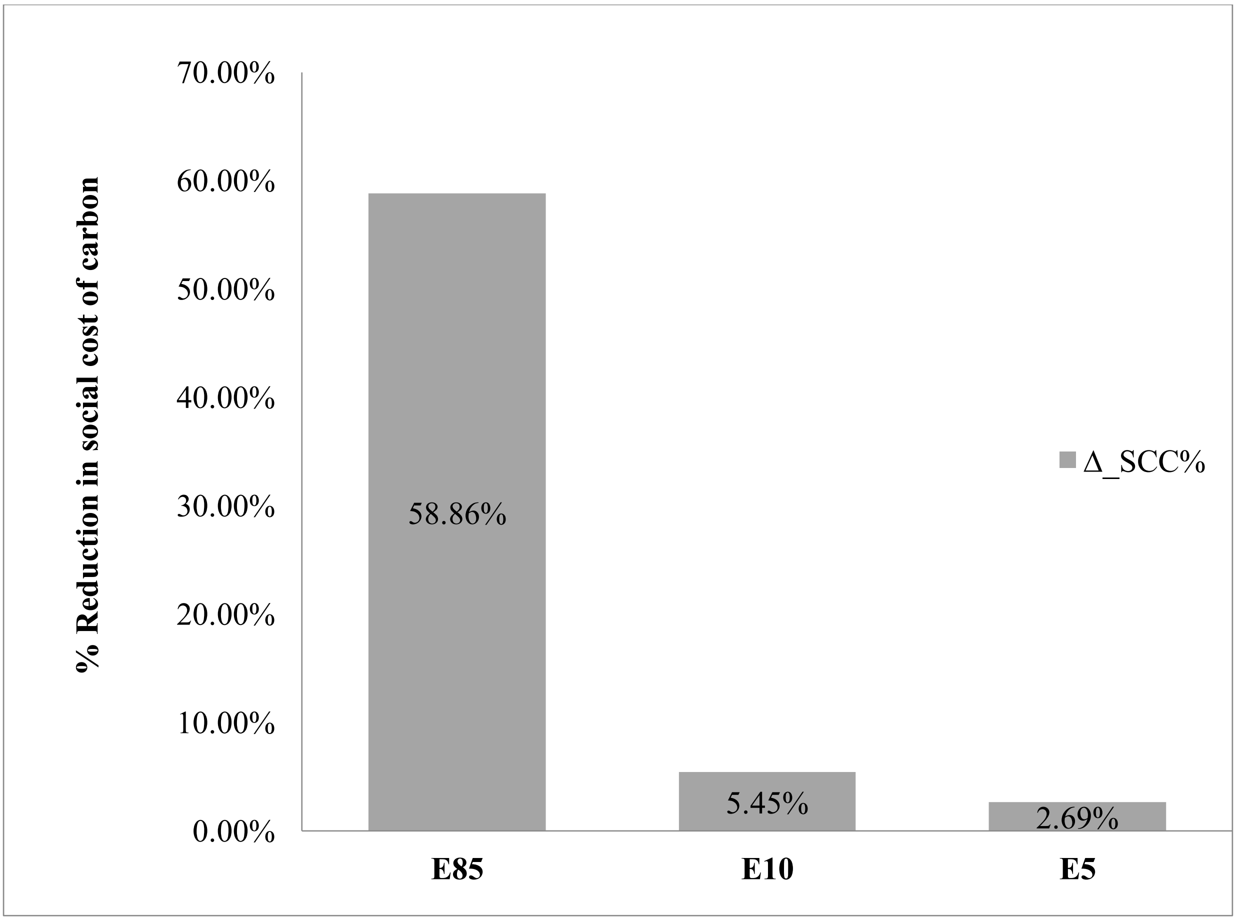


Figure 16: Percentage reduction in social cost of carbon dioxide

The SA annual gasoline consumption is estimated at 6Gl excluding jet fuels [63]. From table 9 based on the gasoline equivalent to E85 (3.47), E10 (37.36), and E5 (75.75) Gl, Ethanol from advanced feedstock in SA dealt in this study in the form of E85, E10, and E5 can be used to fulfill country's energy demand instead of gasoline for 0.57, 6.22 and 12.62 years in the respective order of E85, E10, E5, Figure 17.

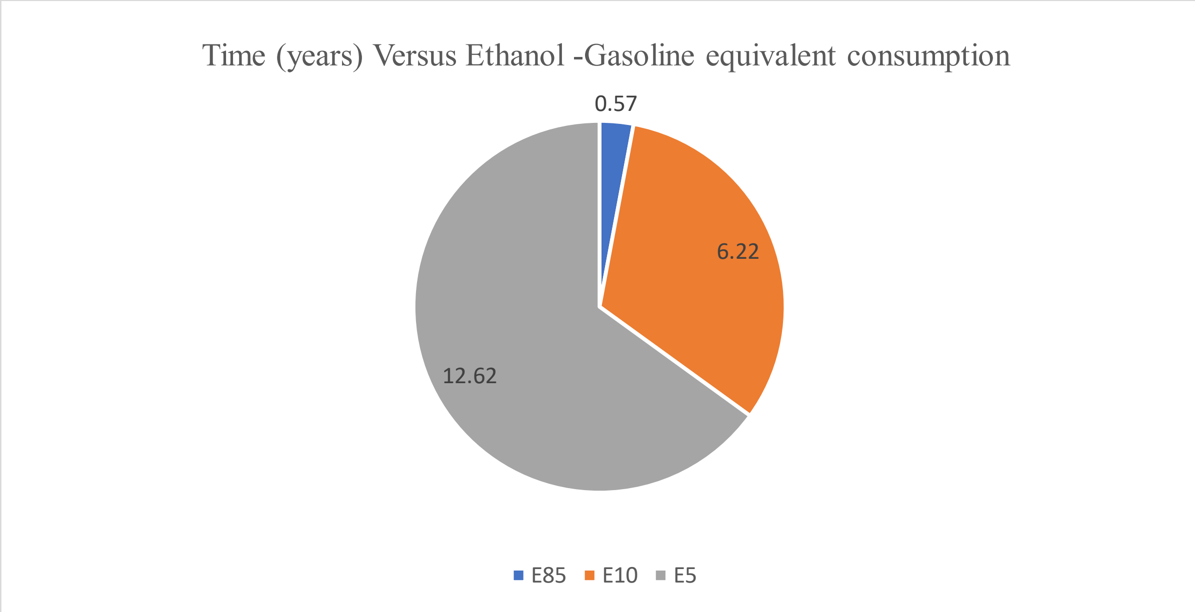


Figure 17: Time that Cellulosic Ethanol can replace Gasoline for different blending quantities

4.4 Sensitivity Analysis

4.4.1 Sensitivity analysis of field cover factor

The change in field cover factor affects the results on collectable residues for biofuel production. Depending on the soil type or crops, when collecting residues, field cover factors may vary from 2t to 4t per ha. Some crops are more highly sensitive on changing field cover factors than others. From Equation (15), we calculated the maximum field cover factors and the results are tabulated in Table 10.

Table 10: Field cover factors and crop yield

Crop	Y_c t/ha	RPR	$(F_c)_{max}$ t/ha
Maize	4.68	2.30	10.78
Wheat	3.24	1.80	5.84
Barley	3.33	1.30	4.34
Sorghum	2.60	2.26	5.89
Rice	2.64	1.70	4.49
Dry beans	1.28	1.70	2.18
Ground nuts	1.36	2.30	3.14
Sunflower seeds	1.26	3.00	3.78
Soy beans	1.72	1.70	2.93
Sugar Cane	65.22	0.35	22.82
Apples	36.65	0.47	17.22
Pears	16.84	0.45	7.57
Apricots	89.26	0.35	31.24
Peaches & nectarines	16.71	0.35	5.85
Plums & sloes	9.22	0.35	3.22
Grapes	16.24	0.06	1.08
Figs	3.05	0.45	1.37
Cherries	2.14	0.83	1.77
Potato	35.10	0.25	8.77
Tomato	72.88	0.3	21.86
Cabbages	57.08	2.3	131.28

From Table 8, even though it is shown that the production quantity of sugar cane is 13 times higher than the production quantity of cabbage, sugar cane is more sensitive to variation in field cover factors Table 10, Figure 18. A crop with higher maximum field cover factor is more sustainable and less sensitive to variation of field cover factors. Negative results in Figure 18 means that collecting residues for soybeans, dry beans, sunflower seeds,plum and sloes, figs, cherries will not be sustainable when field cover factor turns to 4t/ha.

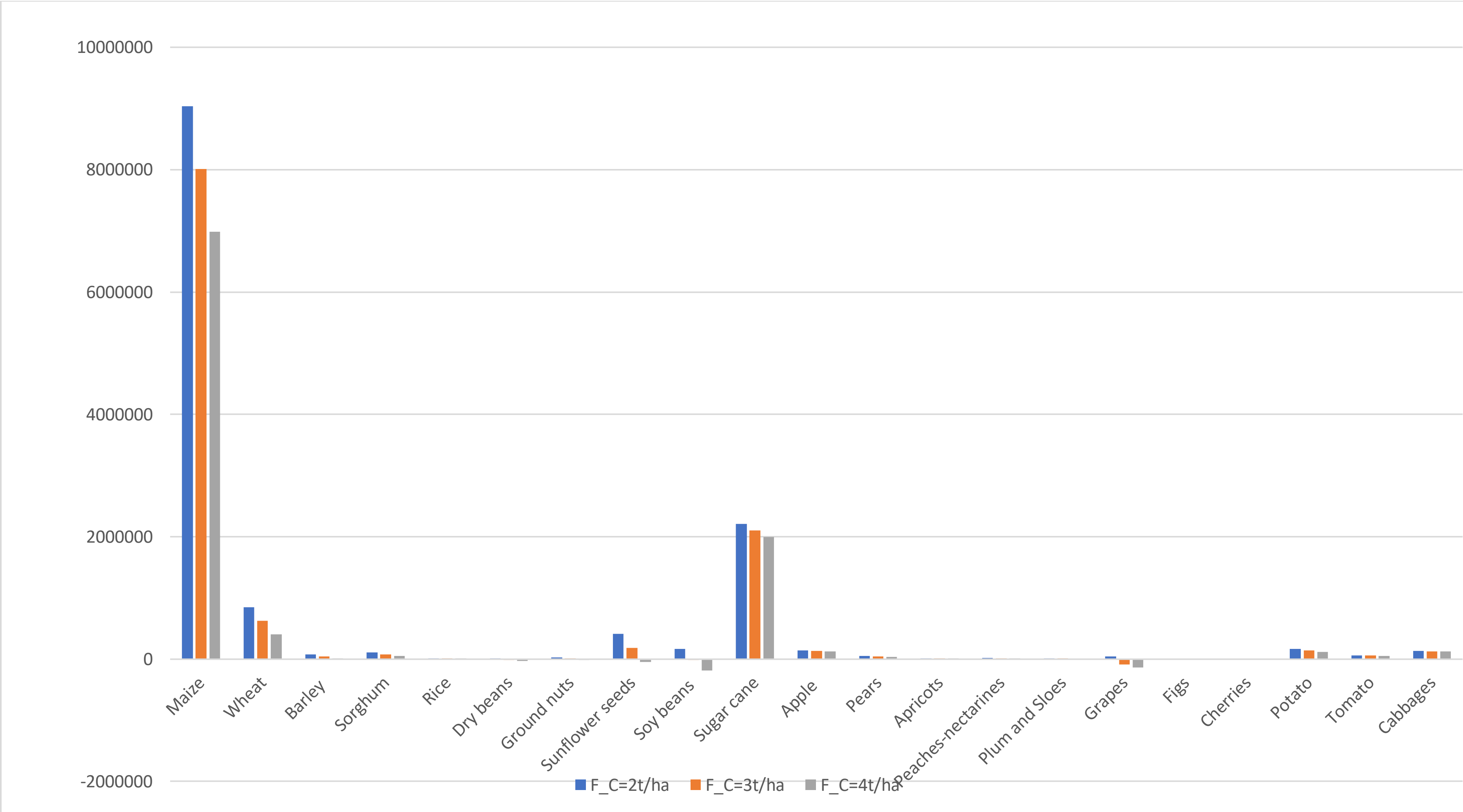


Figure 18: Effect of field cover factor on collectable residues of major crops grown in South Africa

4.4.2 Sensitivity analysis of crop yield

The change in crop yield affects both the production quantity and harvested area which in turn affects the collection area of residues and their quantity. Equation 14 gives the minimum required yield for sustainable residues generation and sustainable biofuel production. The minimum field covers factors for efficient residues collection is 2t per ha. The results computed are tabulated in Table 11. The variation in biofuel production per area harvested given by 20% decrease and 20% increase in the yield from base case are also presented in the same table. The negative results in biofuel yield of dry beans, grapes, figs, and cherries, because of 20% decrease in the yield of those crops implies that residues cannot be taken away from the field for biofuel production.

Table 11: Effect of ± 20% change in crop yields from base case and minimum crop yields

Crops	$(Y_C)_{min}$ (t/ha)	Base case Y_C(t/ha)	Y_b (l/ha) based on		
			Base case Y_C	**-20% Y_C**	**+20% Y_C**
Maize	0.86	4.68	1482.49	1118.47	1482.49
Wheat	1.11	3.24	663.89	461.99	663.89
Barley	1.53	3.33	327.86	206.28	327.86
Sorghum	0.88	2.60	124.73	86.99	124.73
Rice	1.17	2.64	414.83	265.30	414.83
Dry beans	1.17	1.28	23.71	-35.02	23.717
Ground nuts	0.86	1.36	170.76	77.09	170.76
Sunflower seeds	0.66	1.26	141.38	81.42	141.38
Soybeans	1.17	1.72	57.42	21.46	57.42
Sugar cane	5.71	65.22	2249.51	1756.41	2249.51
Sugar cane	4.25	36.65	395.92	306.34	395.92
Apples	4.44	16.84	75.85	55.24	75.85
Apricots	2.40	89.26	350.89	275.91	350.89
Peaches-nectarines	5.71	16.71	46.20	32.16	46.20
Plums and sloes	5.71	9.22	11.42	8.61	11.42
Grapes	5.71	16.24	23.95	-31.62	23.95
Figs	4.44	3.05	-12.49	-17.99	-12.49
Cherries	8.00	2.14	7.94	-20.75	-7.94
Potato	2.40	35.10	569.25	421.80	569.25
Tomato	6.66	72.88	548.27	427.58	548.27
Cabbages	0.86	57.08	2532.71	1854.57	2532.71

The results presented in Table 11 are in conformity with the results presented in figure 18 on the fact that negative values for crop residues given by sensitivity analysis of field cover factors and crop yield suggest to don't use those residues for biofuel production purposes in order to avoid soil degradation and other associated negative consequences which can results from unsustainable use of crop residues.

4.4.3 Sensitivity analysis of collecting and transporting residues.

The cost of transporting residues has almost 60% of the total cost of producing biofuels. It is necessary to limit the cost of transporting residues as low as possible so that production cost of biofuels is lowered. The longer the distance to the biorefinery, the more the transport cost will be and vice-versa. Longer distance from the farm to the biorefinery implies also more GHG emissions depending on the fuel used to power the transportation car. To simplify the analysis, we made an assumption of locating the plant in the middle of the circle. The maximum and average cost of transportation is given by Equations 19 and 20 respectively. Collectable biomass yield given by Equation 13 was calculated and presented in Figure 19 as follows:

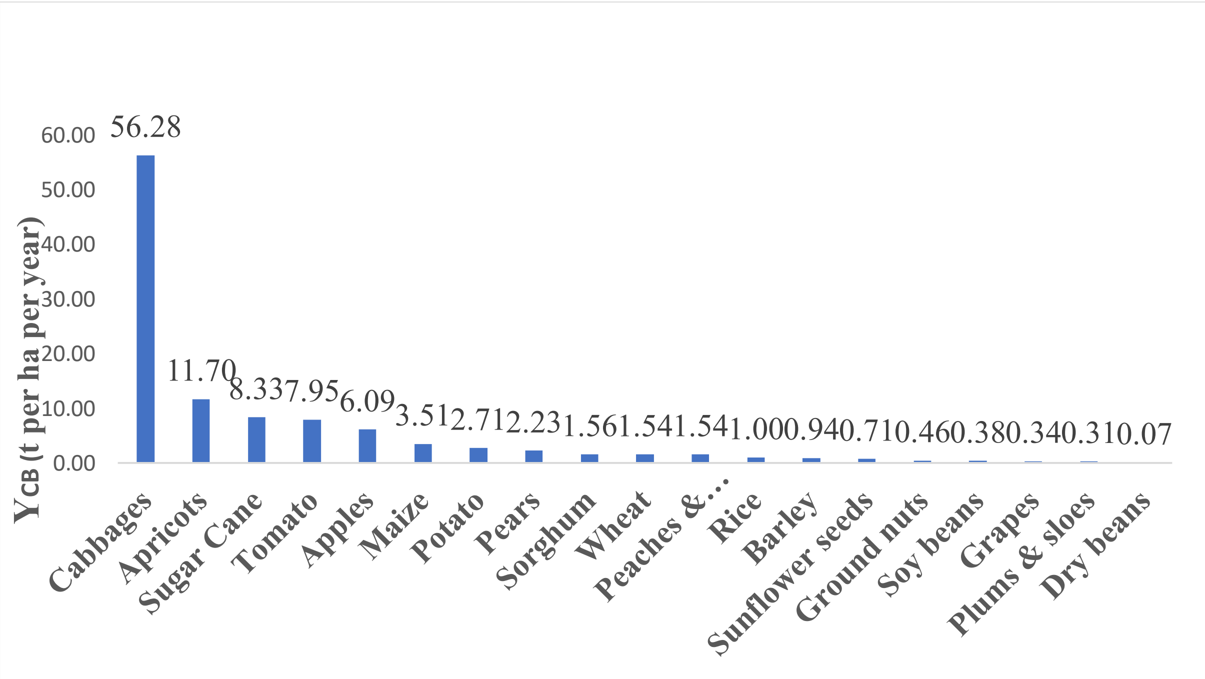
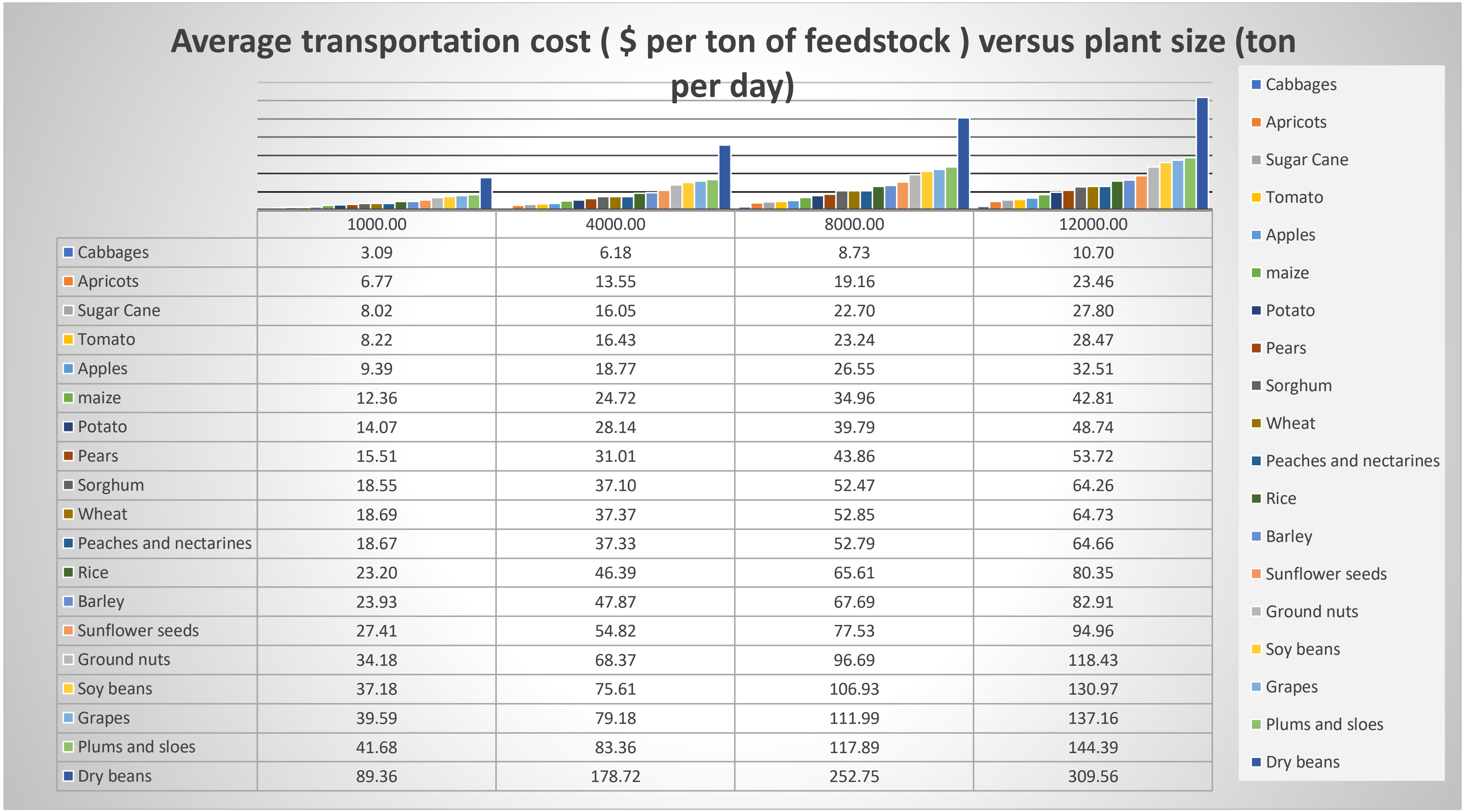


Figure 19: Collectable biomass yield

A careful look on Equations 19 and 20 shows that the small amount of residues per area harvested implies higher cost of transportion. From figure 19 , cabbages have the highest collectable residues (56.28 t per ha per year) . Dry beans have the lowest collectable residues

(0.07t per ha per year). Taking collectable biomass yield values for different crops , fraction of surrounding farmland containing crops (f_L=0.75) and fraction of total available farmaland from which residues can be collected (f_A=0.1) for different plant size , the effect of transportion cost on these residues is shown by figure 20. Dry beans have higher cost of transportation and cabbages have the lowest cost of transportation as a results of different collectable residues per ha per year.



	1000.00	4000.00	8000.00	12000.00
Cabbages	3.09	6.18	8.73	10.70
Apricots	6.77	13.55	19.16	23.46
Sugar Cane	8.02	16.05	22.70	27.80
Tomato	8.22	16.43	23.24	28.47
Apples	9.39	18.77	26.55	32.51
maize	12.36	24.72	34.96	42.81
Potato	14.07	28.14	39.79	48.74
Pears	15.51	31.01	43.86	53.72
Sorghum	18.55	37.10	52.47	64.26
Wheat	18.69	37.37	52.85	64.73
Peaches and nectarines	18.67	37.33	52.79	64.66
Rice	23.20	46.39	65.61	80.35
Barley	23.93	47.87	67.69	82.91
Sunflower seeds	27.41	54.82	77.53	94.96
Ground nuts	34.18	68.37	96.69	118.43
Soy beans	37.18	75.61	106.93	130.97
Grapes	39.59	79.18	111.99	137.16
Plums and sloes	41.68	83.36	117.89	144.39
Dry beans	89.36	178.72	252.75	309.56

Figure 20: Average cost of transportation on different plant size

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the present work studied the feasibility of producing biofuel from crop residues in South Africa. 21 major different crops grown in SA which are grouped into: grains, oilseeds, deciduous fruits and vegetables were used in the study and only 19 have potential to generate residues for biofuel production. An estimated 13.5 Mt of crop residues are potentially available in South Africa per annum to be harnessed for sustainable biofuel production. 2.5 million tons of bioethanol or 4.9 GL of bioethanol can be generated using biochemical conversion route. Life cycle analysis done proved that GHG emissions can potentially be reduced by blending cellulosic ethanol with gasoline fuel. The E85, E10 and E5 blending techniques of bioethanol can serve the country by replacing gasoline during0.57, 6.22 and 12.62 years respectively. The data generated in the present study will serve as a basis for potential investor's decision in bio-refinery industry in South Africa. It will also lessen the burden associated with the use of non-renewable sources of energy in South Africa. Biofuel industry based on crop residues has potential to create more jobs in agricultural sector especially in previously disadvantaged rural areas of South Africa thereby changing the rural habitant farmer's life style and economy. The results presented here are theoretical potential therefore might not be the same technically , as the concept of efficiency and losses will be taken into account in practical situation.

5.2 Recommendation

Information provided in this research will help the government in supporting the development and advancement of second-generation (advanced) biofuels through Biofuel Task Team. The South Africa's 2050 renewable energy target is possible if the present data is combined with other renewable energy sectors such as solar, wind, hydrothermal etc., hence providing a win-win scenario for all stakeholders. The commercialization and initial pilot plant of lignocellulosic biofuel is still a challenge and needs government support in most cases especially subsidies and accelerating research and development, as the industry is still young in the international sphere. The success of biofuel industry in South Africa depends on many factors such as good infrastructure, supply of reliable feedstock and efficient advanced biomass conversion technologies but most importantly, a well-established policy in order to attract potential investors in this industry. Researchers are called to think of integrated bio-refinery which will be able to accommodate any type of feedstock to help in transition from first generation to advanced biofuel production.

REFERENCES

[1] D. Lorne and M. Chabrelie, "New biofuel production technologies: overview of these expanding sectors and the challenges facing them," *IFP Energies nouvelles, Cedex,* 2010.

[2] P. Havlík, U. A. Schneider, E. Schmid, H. Böttcher, S. Fritz, R. Skalský*, et al.*, "Global land-use implications of first and second generation biofuel targets," *Energy policy,* vol. 39, pp. 5690-5702, 2011.

[3] K. DeGhetto, J. R. Gray, and M. N. Kiggundu, "The African Union's Agenda 2063: aspirations, challenges, and opportunities for management research," *Africa Journal of Management,* vol. 2, pp. 93-116, 2016.

[4] Y. Sokona, Y. Mulugetta, and H. Gujba, "Widening energy access in Africa: Towards energy transition," *Energy Policy,* vol. 47, pp. 3-10, 2012.

[5] I. Ozturk and F. Bilgili, "Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries," *Applied Energy,* vol. 137, pp. 110-116, 2015.

[6] W. Y. LIM and A. Seow, "Biomass fuels and lung cancer," *Respirology,* vol. 17, pp. 20-31, 2012.

[7] S. Oparaocha and S. Dutta, "Gender and energy for sustainable development," *Current Opinion in Environmental Sustainability,* vol. 3, pp. 265-271, 2011.

[8] B. Amigun, J. K. Musango, and W. Stafford, "Biofuels and sustainability in Africa," *Renewable and sustainable energy reviews,* vol. 15, pp. 1360-1372, 2011.

[9] S. Mohr, J. Wang, G. Ellem, J. Ward, and D. Giurco, "Projection of world fossil fuels by country," *Fuel,* vol. 141, pp. 120-135, 2015.

[10] R. Heede, "Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010," *Climatic Change,* vol. 122, pp. 229-241, 2014.

[11] Y. Atwa, E. El-Saadany, M. Salama, and R. Seethapathy, "Optimal renewable resources mix for distribution system energy loss minimization," *IEEE Transactions on Power Systems,* vol. 25, pp. 360-370, 2010.

[12] A. Demirbas and M. F. Demirbas, "Importance of algae oil as a source of biodiesel," *Energy conversion and management,* vol. 52, pp. 163-170, 2011.

[13] P. Moriarty and D. Honnery, "What is the global potential for renewable energy?," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 244-252, 2012.

[14] R. A. Lee and J.-M. Lavoie, "From first-to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity," *Animal Frontiers,* vol. 3, pp. 6-11, 2013.

[15] S. Jain, "The production of biodiesel using Karanja (Pongamia pinnata) and Jatropha (Jatropha curcas) Oil," in *Biomass, Biopolymer-Based Materials, and Bioenergy*, ed: Elsevier, 2019, pp. 397-408.

[16] E.-M. Aro, "From first generation biofuels to advanced solar biofuels," *Ambio,* vol. 45, pp. 24-31, 2016.

[17] S. N. Naik, V. V. Goud, P. K. Rout, and A. K. Dalai, "Production of first and second generation biofuels: a comprehensive review," *Renewable and sustainable energy reviews,* vol. 14, pp. 578-597, 2010.

[18] M. W. Rosegrant and S. Msangi, "Consensus and contention in the food-versus-fuel debate," *Annual Review of Environment and Resources,* vol. 39, 2014.

[19] S. A. Mueller, J. E. Anderson, and T. J. Wallington, "Impact of biofuel production and other supply and demand factors on food price increases in 2008," *Biomass and bioenergy,* vol. 35, pp. 1623-1632, 2011.

[20] R. E. Sims, W. Mabee, J. N. Saddler, and M. Taylor, "An overview of second generation biofuel technologies," *Bioresource technology,* vol. 101, pp. 1570-1580, 2010.

[21] A. Mohr and S. Raman, "Lessons from first generation biofuels and implications for the sustainability appraisal of second generation biofuels," *Energy policy,* vol. 63, pp. 114-122, 2013.

[22] B. Antizar-Ladislao and J. L. Turrion-Gomez, "Second-generation biofuels and local bioenergy systems," *Biofuels, Bioproducts and Biorefining,* vol. 2, pp. 455-469, 2008.

[23] UNCTAD, "Second generation biofuel markets: state of play, trade and developing country perspectives," ed: United Nations Geneva, 2016.

[24] L. Kilian, "The impact of the shale oil revolution on US oil and gasoline prices," *Review of Environmental Economics and Policy,* vol. 10, pp. 185-205, 2016.

[25] D. Jaiswal, A. P. De Souza, S. Larsen, D. S. LeBauer, F. E. Miguez, G. Sparovek*, et al.*, "Brazilian sugarcane ethanol as an expandable green alternative to crude oil use," *Nature Climate Change,* vol. 7, p. 788, 2017.

[26] B. Strogen, S. P. Souza, and J. R. Lidicker, "Comment on "Effects of Ethanol on Vehicle Energy Efficiency and Implications on Ethanol Life-Cycle Greenhouse Gas Analysis"," *Environmental science & technology,* vol. 48, pp. 9950-9952, 2014.

[27] D. Sarris and S. Papanikolaou, "Biotechnological production of ethanol: Biochemistry, processes and technologies," *Engineering in life sciences,* vol. 16, pp. 307-329, 2016.

[28] T. Serra, D. Zilberman, J. M. Gil, and B. K. Goodwin, "Price transmission in the US ethanol market," in *Handbook of bioenergy economics and policy*, ed: Springer, 2010, pp. 55-72.

[29] S. de Jong, K. Antonissen, R. Hoefnagels, L. Lonza, M. Wang, A. Faaij*, et al.*, "Life-cycle analysis of greenhouse gas emissions from renewable jet fuel production," *Biotechnology for biofuels,* vol. 10, p. 64, 2017.

[30] Y. Su, P. Zhang, and Y. Su, "An overview of biofuels policies and industrialization in the major biofuel producing countries," *Renewable and Sustainable Energy Reviews,* vol. 50, pp. 991-1003, 2015.

[31] G. Skogstad, "Policy feedback and self-reinforcing and self-undermining processes in EU biofuels policy," *Journal of European Public Policy,* vol. 24, pp. 21-41, 2017.

[32] J. Moncada, M. Junginger, Z. Lukszo, A. Faaij, and M. Weijnen, "Exploring path dependence, policy interactions, and actor behavior in the German biodiesel supply chain," *Applied energy,* vol. 195, pp. 370-381, 2017.

[33] J. R. Moreira, V. Romeiro, S. Fuss, F. Kraxner, and S. A. Pacca, "BECCS potential in Brazil: Achieving negative emissions in ethanol and electricity production based on sugar cane bagasse and other residues," *Applied Energy,* vol. 179, pp. 55-63, 2016.

[34] J. Goldemberg, S. T. Coelho, P. Guardabassi, and P. M. Nastari, "Bioethanol from Sugar: The Brazilian Experience," *Energy from Organic Materials (Biomass) A Volume in the Encyclopedia of Sustainability Science and Technology, Second Edition,* pp. 925-954, 2019.

[35] M. McDermott, M. Cinelli, D. J. Luethge, and P. Byosiere, "Brazil and Biofuels for Autos: A Model for Other Nations," *GSTF Journal on Business Review (GBR),* vol. 2, 2017.

[36] D. Bentivoglio, A. Finco, and M. Bacchi, "Interdependencies between biofuel, fuel and food prices: The case of the Brazilian ethanol market," *Energies,* vol. 9, p. 464, 2016.

[37] K. A. Smith and T. D. Searchinger, "Crop-based biofuels and associated environmental concerns," *Gcb Bioenergy,* vol. 4, pp. 479-484, 2012.

[38] L. Ruan, A. K. Bhardwaj, S. K. Hamilton, and G. P. Robertson, "Nitrogen fertilization challenges the climate benefit of cellulosic biofuels," *Environmental Research Letters,* vol. 11, p. 064007, 2016.

[39] G. Prasad, "Bioenergy, rural development and poverty alleviation in Southern Africa," *Cape Town: Energy Research centre,* 2010.

[40] A. Pradhan and C. Mbohwa, "Development of biofuels in South Africa: Challenges and opportunities," *Renewable and Sustainable Energy Reviews,* vol. 39, pp. 1089-1100, 2014.

[41] L. R. Lynd, M. Sow, A. F. Chimphango, L. A. Cortez, C. H. B. Cruz, M. Elmissiry*, et al.*, "Bioenergy and African transformation," *Biotechnology for biofuels,* vol. 8, p. 18, 2015.

[42] J. A. Flores, O. Konrad, C. R. Flores, and N. T. Schroder, "Sustainability indicators for bioenergy generation from Amazon's non-woody native biomass sources," *Data in brief,* 2018.

[43] M. A. Carriquiry, X. Du, and G. R. Timilsina, "Second generation biofuels: Economics and policies," *Energy Policy,* vol. 39, pp. 4222-4234, 2011.

[44] S. K. Rose, E. Kriegler, R. Bibas, K. Calvin, A. Popp, D. P. van Vuuren*, et al.*, "Bioenergy in energy transformation and climate management," *Climatic Change,* vol. 123, pp. 477-493, 2014.

[45] O. Shortall, "“Marginal land” for energy crops: Exploring definitions and embedded assumptions," *Energy Policy,* vol. 62, pp. 19-27, 2013.

[46] Worldatlas, "Geographical location of South Africa," 2017.

[47] FAOSTAT. Food and Agriculture Organization of the United Nations, Statistics Division [Online]. Available: http://www.fao.org/faostat/en/#data/OA

[48] S. Jain and P. Jain, "The rise of renewable energy implementation in South Africa," *Energy Procedia,* vol. 143, pp. 721-726, 2017.

[49] K. Ratshomo and R. Nembahe, "South Africa Energy Sector Report," 2018.

[50] F. a. F. Departement of Agriculture, "South Africa yearbook," DAFF2017/2018.

[51] J. K. Saini, R. Saini, and L. Tewari, "Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments," *3 Biotech,* vol. 5, pp. 337-353, 2015.

[52] R. Chandra, H. Takeuchi, and T. Hasegawa, "Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production," *Renewable and Sustainable Energy Reviews,* vol. 16, pp. 1462-1476, 2012.

[53] M. Taherzadeh and K. Karimi, "Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: a review," *International journal of molecular sciences,* vol. 9, pp. 1621-1651, 2008.

[54] T. Damartzis and A. Zabaniotou, "Thermochemical conversion of biomass to second generation biofuels through integrated process design—A review," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 366-378, 2011.

[55] M. K. Alavijeh and S. Yaghmaei, "Biochemical production of bioenergy from agricultural crops and residue in Iran," *Waste management,* vol. 52, pp. 375-394, 2016.

[56] A. Eisentraut, "Sustainable production of second-generation biofuels," 2010.

[57] H. Escalante, L. Castro, P. Gauthier-Maradei, and R. R. De La Vega, "Spatial decision support system to evaluate crop residue energy potential by anaerobic digestion," *Bioresource technology,* vol. 219, pp. 80-90, 2016.

[58] M. Hiloidhari, D. Das, and D. Baruah, "Bioenergy potential from crop residue biomass in India," *Renewable and sustainable energy reviews,* vol. 32, pp. 504-512, 2014.

[59] A. Koopmans and J. Koppejan, "Agricultural and forest residues-generation, utilization and availability," *Paper presented at the regional consultation on modern applications of biomass energy,* vol. 6, p. 10, 1997.

[60] R. Lal, "World crop residues production and implications of its use as a biofuel," *Environment International,* vol. 31, pp. 575-584, 2005.

[61] C. Di Blasi, V. Tanzi, and M. Lanzetta, "A study on the production of agricultural residues in Italy," *Biomass and Bioenergy,* vol. 12, pp. 321-331, 1997.

[62] L.-Q. Ji, "An assessment of agricultural residue resources for liquid biofuel production in China," *Renewable and Sustainable Energy Reviews,* vol. 44, pp. 561-575, 2015.

[63] T. g. Economy.com. (2016, 10th July). *Economic indicators for over 200 countries* https://www.theglobaleconomy.com/South-Africa/gasoline_consumption/.

APPENDICES

A1. Research Budget

Number	Item	Unity	Quantity	Rate	Total Amount in SA Rands	In Dollars ($)	Link to research Activity
Material and Supplies							
1	Internet	Months	5 Months	1431.59/Month	7157.95	500	Articles, YouTube information
2	Communication/Airtime	Months	5 Months	45/Month	644.75	225	Direct calls for discussing with supervisor thesis progress
3	Research assistant	Months	5 Months	1431.59/Month	7157.95	500	Data entry, chemistry course coaching
4	Printing/Photocopy	Months	5 Months	1791.64/Month	8958.2	625	Printing Articles, books, documents for literature reviews and binding books for submission
5	Data analysis training fees	Days	3	1431.59	4294.77	300	To be well trained before actual research data analysis
Sub total					28 213.62	2150	
Travel expenses							
1	Postponing ticket fees	NA	NA	NA	1204.56	84.14	A delay has been made which prevented to begin on time
2	Private taxi from Tlemcen to Algiers and from Algiers to tlemcen	NA	NA	NA	1567.96	109.39	Departure and coming back for research
3	Visa fees	NA	NA	NA	573.72	40.01	Required documents prior to research
4	Medical insurance fees	NA	NA	NA	2 453.47	171.10	Required documents prior to research
5	Private taxi from cape town airport to accommodation and back to airport	NA	NA	NA	600.75	41.89	Arrival and departure fro south Africa

Sub total					6 400.46	446.53	
Special activities							
1	Paper publication, Conference, and workshops	NA	NA	NA	2863.18	200	Publishing research article
2	Contingencies				2870.4	203.47	Un expected events which may arise during research period
Sub total						403.47	
General Total					43 018.20	3000	

A2. Turnitin Originality Report