A PLATFORM FOR STAKEHOLDERS IN AFRICAN FORESTRY

DEVELOPING CIRCULAR ECONOMIES IN EASTERN AFRICA COUNTRIES THROUGH LIQUID BIOFUELS: CASES OF ETHIOPIA, KENYA, AND TANZANIA

VOLUME 5 ISSUE 6

 African Forest Forum P.O. Box 30677 00100 Nairobi GPO KENYA Tel: +254 20 7224203 Fax: +254 20 722 4001. E-mail:exec.sec@afforum.org Website: www.afforum.org. Twitter @ africanff. Facebook /African Forest Forum. LinkedIn /African Forest Forum (AFF).

Citation: Kedir, M.F., Onchieku, M.J., Ntalikwa J.S., Mutta D. (2022) *Developing circular economy in Eastern Africa through liquid biofuels: cases of Ethiopia, Kenya and Tanzania*. AFF Working Paper. African Forest Forum, Nairobi.

Cover photos (L-R): Section of cut sugarcane plantation/courtesy; Castor/courtesy; Hanging fruits (via Wikimedia Commons).

Developing circular economy in Eastern Africa through liquid biofuels: cases of Ethiopia, Kenya and Tanzania

Miftah F. Kedir (Ethiopia)
James M. Onchieku (Kenya)
Scolastica J. Ntalikwa (Tanzania)
Doris Mutta (African Forest Forum)

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ACRONYMS/ ABBREVIATIONS

AFF	African Forest Forum
2DS	2 degrees centigrade scenario
COMESA	Common Market for Eastern and Southern Africa
EMD	Ethanol Micro Distillery
FELISA	Farming for Energy for Better Livelihoods in Southern Africa
FWFCA	Former Women Fuelwood Carriers Association
GHG	Greenhouse Gases
ICRAF	International Center of Research in Agroforestry-World Agroforestry
KAKUTE	Kampuni ya Kusambaza Teknolojia
KEBS	Kenya Bureau of Standards
KNBS	Kenya National Bureau of Statistics
MEM	Ministry of Energy and Minerals
MNRT	Ministry of Natural Resources and Tourism
MoE	Ministry of Energy
MoWIE	Ministry of Water, Irrigation and Energy
NGO	Non-Governmental Organization
RTSBP	Round Table for Sustainable Biofuel Production
Sida	Swedish International Development Cooperation Agency
SNNPR	Southern Nations and Nationalities People Region
TATEDO	Tanzanian Traditional Energy Development and Environment Organisation
TIC	Tanzania Investment Centre

DEFINITIONS

- Traditional biomass fuel: unprocessed biomass fuel: firewood, crop residues, and animal dung.
- Advanced biofuels: second generation liquid biofuels obtained from residual biomasses of lignocellulosic type
- Agro fuels: use of agricultural product for fuel. Since agricultural resources are also biological, biofuel is the broader term encompassing agro fuel.
- Biodiesel: a liquid fuel produced from vegetable oil or animal fats.
- Bioenergy: biomass energy derived from biofuel or recently living biomass, that produce heat and/or electricity from solid, liquid and gaseous fuels for transportation, heat and/or electricity generation. Biomass energy, or bioenergy, is obtained when biomass is converted into electricity, heat, power, or transportation fuels.
- Bioethanol: ethanol produced from sugary or starchy biomass (root, stem, leaves, and seed) and/or biodegradable fraction of waste.
- Biofuel generations: are defined as 1st, 2nd, 3rd and 4th generations. First generations are biofuels derived from crops like soya bean, maize, jatropha, sugarcane etc. Second generation biofuels are derived from lignocellulosic biomasses including harvested wood, residues, and wastes used for biofuel production. Third generation biofuels are derived from micro-algae and seaweeds that have less dependence on land. Fourth generations are derived from genetically modified plants.
- Biofuel: use of biological materials for fuel, such as wood, residue, dung, bagasse etc. in the form of solid, liquid or gases. Fuels are produced directly or indirectly from biomass such as firewood, charcoal, bioethanol, biodiesel, biogas (methane) or biohydrogen. There are solid biofuels, liquid biofuels or gaseous biofuels.
- Biomass: non-fossilized material of biological origin, derived from plants, animals or algae such as energy crops, agricultural and forestry residue/ wastes and by-products, or manure.
- Circular economy: economy in which products and materials are recycled, repaired and reused rather than thrown away
- Conventional biofuels: solid firewood or liquid and gaseous fuel produced from biomass including, bioethanol, biodiesel and biogas.
- Feedstocks: any processed or unprocessed biomass materials that are acting as a raw material for further manufacturing process.
- Liquid biofuels: alcohols, esters, ethers, and other chemicals and bio additives such as bioethanol, biodiesel, biobutanol, biomethanol, bioETBE (ethyl tert-butyl ether), bioMTBE (methyl tert-butyl ether), biogasoline, and combustible oils produced by plants.
- Primary energy: energy form found in nature that has not been subjected to any human engineered conversion process including unconverted or original fuels that can be mined, reaped, extracted, harvested, or harnessed directly; e.g. petroleum, crude oil, natural gas, nuclear energy, hard coal, biomass, flowing water, geothermal, wind, solar radiation, hydroelectricity, wave, and tidal energy.
- Secondary energy: all energy obtained from chemical or physical transforming primary energy (in particular electricity of thermal origin); e.g. gasoline is a secondary fuel, as it must be made from oil through distillation processes.
- Pyrolysis oil: a dark-brown, free flowing liquid made from plant material by a process called pyrolysis, whereby biomass particles are rapidly heated to 400 to 600°C in the absence of oxygen, vaporized and the vapours are condensed into liquid pyrolysis oil, also known as bio-oil.

Conversion Units:

(a) Currency Conversion

US $ 1	46 Ethiopian Birr (ETB) in 2020
US $ 1	100.35 Kenyan Shilling (KES) in February 2020

(b) Unit Conversion Table

1 tonne	1000 kilograms
1 acre	4047 sq. metres
1 cubic metre	1000 litres
1Gallon	3.785 litres
1 Barrel	42 US Gallons

ACKNOWLEDGEMENT

This study was financially supported by the African Forest Forum project on "Strengthening Management and Use of Forest Ecosystems for Sustainable Development in Africa" as a part of Swedish International Development Agency (Sida) support to AFF. The local people, experts and officials at different institutions of Federal, regional and district level of Ethiopia, Kenya and Tanzania who had direct and indirect involvement during the study deserve special thanks.

EXECUTIVE SUMMARY

The African Forest Forum (AFF) has undertaken studies in four African sub-regions to assess the potential of selected African countries to produce and use of liquid biofuels as a strategy for developing green and circular economies. The sub regions are eastern, southern, central and western Africa. This report is on three eastern Africa countries namely of Ethiopia, Kenya and Tanzania. Then the outputs of this study are expected to facilitate planning the growth and development of local and national liquid biofuel sector based on information and data obtained from field and factory visits, interviews and discussions with some national government and Non-Governmental Organizations (NGOs), and other stakeholders related to the liquid biofuel industry.

Liquid biofuels commonly available in eastern Africa are bioethanol and biodiesel produced from higher plants, though there was ongoing research on liquid biofuel from microalgae. In Ethiopia, land highly suitable for production of feedstock was estimated that 7.2 million ha (6.3%) for jatropha, 7.68 million ha (6.8%) for croton, 11.47 million ha (10.2%) for cassava, 40.91 million ha (36.2%) for sweet sorghum, and 0.7 million ha (0.62%) for sugarcane. In Kenya, 17.4 million ha (30.6%) land area was suitable for sweet sorghum, 6.39 million ha (11.2%) for cassava, 1.26 million ha (2.2%) for sugarcane, and 14.9 million ha (26.2%) for jatropha. In Tanzania, the suitable land area is 22.79million ha (22.9%) for cassava, 18.96million ha (21.5%) for sugarcane, 31.51million ha (35.8%) for sweet sorghum, and 17.78million ha (20.2%) for sunflower.

Investments in liquid biofuel production in the years 2010s were not profitable, resulting in investors abandoning investments on feedstocks like jatropha and related biodiesel crops. The only investment that remained was the already well-known sugarcane production mainly for sugar and molasses bioethanol. The use of sugarcane for the production of biofuels has been observed in13 sugar factories in Ethiopia, 16 sugar factories in Kenya, and five sugar factories in Tanzania. The reported annual production of ethanol was 24.25 million liters in Ethiopia, 8.25 million in Kenya and 1.4 million in Tanzania from one or two sugar factories.

Improving productivity of sugarcane by increasing the yield to 138 tons or more per hectare, combined with improvement in technology by reducing wastage in molasses, and ethanol production, could enable the existing Ethiopian sugarcane factories to produce in full capacity at 432.41 million liters of ethanol per year, and those in the Kenyan at 289.28 million liters/year and the ones in Tanzanian at 81.64 million liters/year, when operating on an average of 250 working days/year.

The production costs for conventional liquid biofuels are mainly the feedstock costs that account for 60-90% of the total production cost. This has given rise to the use of cheap sources such as lignocellulosic biomass waste, agricultural residues, and sugarcane bagasse. These were reported to vary annually from about 2.2 million tons of agricultural residues in Kenya, to 19.7 million tons in Ethiopia, in addition to 24.2 million tons of woody biomass residues in Kenya to 105.2 million tons in Ethiopia that could be used for lignocellulosic bioethanol production. From lignocellulosic biomass processing, the total bioethanol production could reach 8.2 billion liters/year in Kenya, 10.8 billion liters in Tanzania to 35.7 billion liters/year in Ethiopia, which is higher than their imports of petroleum.

Bio-oil (pyrolysis oil) is another liquid biofuel that can be obtained by burning biomass at 400 to 1000°C under limited oxygen environment. Pyrolysis oil producing biomass includes *eucalyptus* species, in addition to other biomass resources. Microalgae oil is identified as a potential biodiesel feedstock in Ethiopia, Kenya and Tanzania as these tropical countries have favorable climatic conditions. Microalgae are promising liquid biofuel feedstock due to its rapid growth rate and many times harvest, and without taking up land under food crops or forests. Microalgae can produce 11,238litres biodiesel per hectar per year, which is higher than the 150litres biodiesel from a hectare of jatropha and higher than the 700 liters of ethanol in a hectare of sugarcane.

The use of ethanol for cooking at household level reduces emission that can be created by solid biomass fuel including 99.8% of particulate matter created by burning solid biomass in three stone stoves and 91.0% of that created by wood/charcoal Rocket Combo stoves. Improving the E15 in Ethiopia could have an abatement potential of 0.2 Mt CO_2^e in 2030. In Kenya, adoption of low carbon using biodiesel has an abatement potential of 1.2 $MtCO_2^e$. Tanzania has a commitment to reduce greenhouse gas emissions economy-wide between 138 - 153 $MtCO_2^e$ by 2030 by promoting clean technologies.

The eastern Africa national governments ambitious plans to produce liquid biofuel had minimal achievements because of institutional, market, technical and legal challenges. Many of these can be overcome by providing comprehensive support for out growers, supporting seed production and diversifying feedstock, in addition to providing training and financial incentive, as well as researching different types of feedstocks that have high yield. There are also needs to improve water use efficiency in production and providing supportive/enabling policies.

Also, the liquid biofuel investment in eastern Africa had adversely affected crop land in many places because it was not based on pre-assessment of land-use. Much as there was and continues to exist good potential domestic and foreign markets for liquid biofuel, the failure on the initial biofuel production investment resulted in idleness of land that was allocated to production of feedstock and supporting infrastructure, mistrust between local people who lost land and the investors, and loss of labour. That notwithstanding, given the new impetus on renewable energy, forestry and agricultural professionals should aggressively continue researching on appropriate and productive bioenergy crops.

1.INTRODUCTION

The African Forest Forum (AFF) has undertaken studies in four African sub-regions on the potential of African countries to produce and use of liquid biofuels as a strategy for developing green and circular economies. Liquid biofuel production and utilization continues to receive global attention because of the need to reduce emissions from use of fossil fuels, to supply alternative energy sources due to depletion of fossil fuel reserves, and to promote growth in local economies. These studies have been supported by a grant from the Swedish International Development Cooperation Agency (Sida) that funded project entitled "Strengthening Management and Use of Forest Ecosystems for Sustainable Development in Africa", which examined the potential for biofuel production in eastern, southern, central, and western Africa. This report is on the liquid biofuels production and use in three eastern Africa countries namely Ethiopia, Kenya, and Tanzania. Liquid biofuels are clean renewable energy sources that contribute to climate security and energy access. They also improve air quality of the environment given that reliance on fossil fuel has increased, in the atmosphere, energy-related CO_2 emissions from 277ppm in 1750 to 417ppm in March 2021[1].

Globally, about over 2.7 billion people will not have access to clean cooking energy by 2030 (OECD/ IEA, 2017). According to IEA (2019), 850million people globally and over 550 million people in Africa (48% of the world population) have no access to electricity (OECD/IAE, 2017), demonstrating deep disparities given the promise of 'clean energy for all', and indicating that the pace of renewable-driven energy transitions is slow. Also, lending weight to clean energy is the Paris Agreement that informs that holding the rise in world temperatures to "well below 2°C and limit to 1.5°C" cannot be attained without bioenergy (Brito Cruz *et al*., 2014; Rogelj *et al*., 2016). IEA (2021) identifies bioenergy as one of the seven "key pillars" of decarbonisation for getting to Net Zero by 2050. Biofuels are reported to have the capacity to reduce Greenhouse Gases (GHG) emissions by 10–90% relative to fossil fuels (Kartha and Larson, 2000). The main commercialized transport liquid biofuels made from biomass materials are sugarcane and corn for bioethanol, and soybean and palm oil for biodiesel, and these fuels can be used purely or as blends. The global market shares of biofuels in 2017 were 64% bioethanol and 36% biodiesel (Trent, 2019). Circular economy (CE) is argued to be one of the solutions to overcome global sustainability challenges and deforestation through closing resource loops by regenerating, circulating by reducing, reusing, recycling or remanufacturing the output of one material to the input of the other, and also restoring materials and nutrients in the biosphere. The use of residual lignocellulosic biomass (such as harvest and processing wastes) for the production of liquid biofuels does not depend on the land area and food or feed crop use but is one way of promoting circular economy.

African countries have made investments in such green energy. A number of biofuel feedstocks including jatropha, castor, palm oil, soya bean, sunflower, sugarcane, cassava, sweet sorghum, maize, potatoes, macadamia, etc., have been growing under a wide range of African altitudes, temperatures and rainfall conditions. Several studies indicate the existence of enough arable land on the continent for both food and bio-energy feedstock cultivation for national and export markets. Some African countries

[1] https://www.weforum.org/agenda/2021/03/met-office-atmospheric-co2-industrial-levels-environment-climate-change

have biofuel strategic plans, with some having allocated 10-20.6% of their land to energy crops. However, the evolving picture is one of an unclear development of the biofuel industry on the continent; making it important to understand the status of the biofuel industry and what guidance individual countries can solicit and use in developing policies and regulations to guide the industry (Agenda 2063, 2014). This is especially important, given that increasing economic activities and a rising national population would lead to higher domestic energy demand, which is mostly satisfied by imports of foreign produced energy.
Using the blend of different amounts of liquid biofuels, mainly bioethanol and biodiesel as alternative fuels, to conventional fossil fuels is an important option to reduce petroleum fuel consumption and holds potential to reduce GHG emissions. Biodiesel reduces emissions of carcinogenic compounds by as much as 85% compared with petro-diesel (Yage et al., 2009). Transport sector emissions that have been estimated for Ethiopia, Kenya and Tanzania in 2020 and 2030 in business as usual are respectively 10 and 26; 10 and 19; and 8 and 17 $MtCO_2^e$. At the low carbon level, the estimated transport emissions for Ethiopia, Kenya and Tanzania in 2020 and 2030 are 8 and 19; 7 and 12; and 7 and 12 $MtCO_2^e$ (ibid).

Solid biomass and kerosene combustion in residential buildings, commercial and institutional facilities, manufacturing industries and construction emit GHGs which can be substituted by liquid biofuel. Through increasing urbanization, rising household incomes, and potential low electricity prices, families are expected to switch to hydroelectricity as a cheaper and cleaner alternative. However, at national level hydroelectricity production can considerably be influenced by climate change that affects open water storage, while biomass-based energy sources appear to be less influenced by climate change as the sources are diverse and have better water use efficiency (Kedir, 2014). Production and utilization of liquid biofuels in Africa could strengthen management and use of forest ecosystems for sustainable development, reduce dependence on solid biomass fuels, address poverty eradication and environmental protection and reduce indoor pollution. Liquid biofuels are needed to reduce import expenditure, GHG emissions and meet the green economy targets (CRGE, 2011). Africa is reported to have biofuel development strategies since 2007 that targeted to increase the role of biofuel in reducing the import of petroleum; however, this has not borne much fruit in terms of an actual growth in biofuel industry due to several bottlenecks. Accordingly, this study reported on investigated the scale of production of liquid biofuels, existing and likely future opportunities, or prospects, in addition to the challenges in production and use of biofuels in eastern Africa; with the aim being to facilitate planning the growth and development of local, national and sub-regional liquid biofuel sector and circular green economy.

The objectives of the study were to: assess trends on biofuel production, processing and consumption and greenhouse gas emission; evaluate opportunities, and challenges in the production and use of biofuels, as well as coping mechanisms; assess the effect of liquid biofuel production on food cropland and in primary forest margins and implications on food security and primary forest cover loss (deforestation and forest degradation); assess the competitiveness of African biofuels in the international market; and identify policy, regulatory and institutional frameworks relevant to the sustainable production, processing, transport and consumption of liquid biofuels in the context of changing climate.

2. MATERIALS AND METHODS OF THE STUDY

The materials used for the study were pretested interview questionnaires and Global Positioning System (GPS). The locations of the field studies are shown in Figure 1.

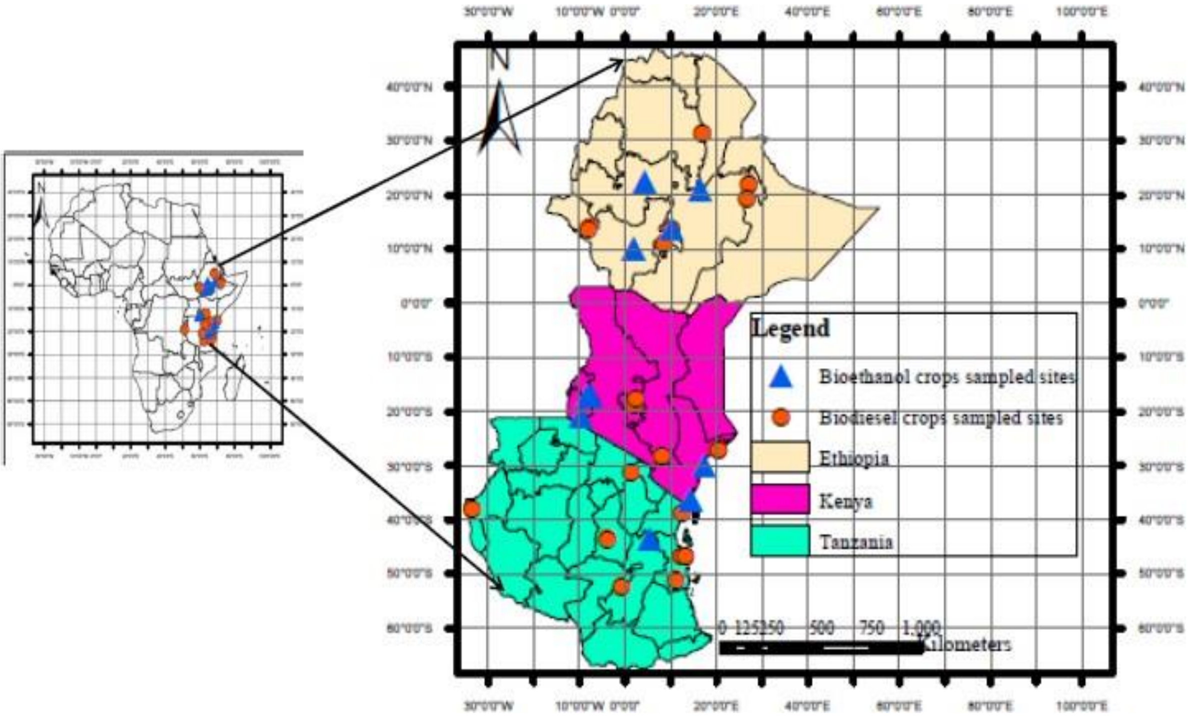

Figure 1: Location of the field study sampled areas (Source: Authors)

2.1 Study areas and data collection procedures

Different regions of Ethiopia, Kenya and Tanzania were assessed and 15, 23, and 17 key informants, respectively were identified and recruited from a constellation of producers and processors of feedstock, research institutions and universities, relevant lead agencies, national and international NGOs, and with 11, 11, and 13 focused groups, respectively. In Ethiopia, these were the Addis Ababa Federal Rural Energy Coordination Office; Oromia Region Energy Office, Delomena woreda energy sector; Amhara Regions', Bati woreda Eftu Biofuel Association; Southern Nations Nationalities People Region (SNNPR), Dara woreda energy sector, Wolaita Sodo and Sawula woreda energy and environment sector; Metahara and Fincha Sugar factories. In Kenya, country experts on liquid biofuels were selected in Nairobi, Coast, Central, Southeastern and Nyanza regions as potential sources of data. In Tanzania, the data was collected from different regions and institutions Dar es Salaam: Sun-biofuels, Mafuta Sasa Biodiesel Ltd in Temeke district; Arusha: Engaruka village in Monduli district, Ngarinairobi Village in the Arumeru district, and Kigoma: Farming for Energy for Better Livelihoods in Southern Africa (FELISA) Co. Ltd., Agrisol Energy Ltd.; Tanzanian Traditional Energy Development and Environment Organization (TaTEDO), Kampuni ya Kusambaza Teknolojia (Kakute); and Kilombero Sugar Company.

In the study primary and secondary data sources were assessed in February to May 2021**.** The primary field data was collected by purposive sampling technique and interviews on the technical and socioeconomic aspects related to the production and use of liquid biofuel. Purposive sampling technique is widely used in qualitative research for the identification and selection of information-rich cases related to the phenomenon of interest (Palinkas et al., 2015).
Key informants were interviewed about the past activities and status of biofuel by using pretested structured and semi-structured questionnaires. The assessment of biofuel condition was carried out based on guidance of experts of energy and environment sectors. The soil, rainfall, temperature, elevation, and land use/ land cover conditions of biofuel crops sites were assessed, and land suitability analysis was obtained from literature.

In Ethiopia, the suitability analysis excludes environmentally sensitive lands (e.g forests, parks, wildlife sanctuaries, and marshy areas, and cultivated lands for crop production) (Geremew et al., 2016) and calculated as the proportion of 112.87 mha surface areas. In Kenya, protected areas, wildlife conflict areas, wetland areas, important bird areas, slopes more than 45% and animal movement paths were excluded (Muok et al, 2010; Ndegwa et al., 2011) and calculated as the proportion of 56.86 mha surface areas. In Tanzania, the suitability analysis was based on subsistence-type production system with low capital input by using traditional or modern cultivars of crops suitable outside cash & food crop area with tilling that uses hand labour and traditional tools and calculated as the proportion of 88.107mha (Kassam et al., 2012; Wiggins et al., 2011).

The interview responses obtained from the small-holder farmers and their associations were triangulated with the respective district development agents, official government reports, and private sectors. The emissions were compared and based on the availability of liquid biofuel from previous literature. Then qualitative data were analyzed by narration and summarization.

3. RESULTS AND DISCUSSION

Liquid biofuels commonly available in eastern Africa were bioethanol and biodiesel produced from higher plants. The study also observed ongoing research on the identification of microalgae.

There were four systems of production of feedstocks including large-scale company plantations, out-growers scheme through contract agreement, community participation and individual smallholders. The major ways of cultivating biofuel crops were as live fences; on community based degraded lands, as out grower farmers in community agricultural lands, and on large scale plantation of grazing or cleared forest land.

3.1 Land allocated for liquid biofuel crops production

It is estimated that Africa holds more than 60% of the world's uncultivated arable land but has low productivity and is a net importer of food (OBG, 2019). However, there is great potential for future production of different types of crops. For example, eastern Africa has abundant suitable land (Table 1) that can be used for major crops, especially in the equatorial areas that include Ethiopia, Kenya and Tanzania that are highly suitable for different types of biofuel crops such as jatropha, castor, croton, cassava, cotton, sweet sorghum, oil palm, and sunflower. It is therefore, important that for the production of sufficient food and biofuel, the productivity of land per unit area and per unit time is improved.

Areas with annual rainfall of less than 600 and above 1,500 mm, average daily temperature of less than 17°C and higher than 28°C, as well as soil type of heavy clay are not suitable for biofuel production. Areas with precipitation between 600 to 1000 mm, elevation of 1,500 to 2,150 meters, temperature range of 17 to 20 °C, and with a small proportion of clay and little water logging potential are suitable for biofuel feedstock production. However, landsuitabilty varies through time because of agroclimatic characters, climate change, soil fertility management, and fertigation.

In Ethiopia, the potentially available land for bio-energy oil crops has been estimated at 23.3 million hectares (CRGE, 2011) out the total 112.87 million ha of the country's land area. However, based on rainfall, temperature, soil type and altitude it was estimated that about 7.12m ha (6.3%) are highly suitable for jatropha and 7.68 mha (6.8%) for croton (Geremew et al., 2016). Further, about 0.7 mha (0.62%) is found to be suitable for the production of sugarcane (Table 1); and with available continuous irrigation, about 4 mha can be suitable for sugarcane (EMoMPNG, 2018). Large scale biofuel investments on land covering over 2000 ha were made in different parts of Ethiopia by private investors. However, in 2021 there were no private investors for biodiesel production, and all terminated the investment in 2016.

Table 1. Highly suitable land for different biofuel crops production

Biofuel crop type	Ethiopia*		Kenya**			Tanzania***	
	Land area (million ha)	Land area (%)	Land area (million ha)	Land area (%)		Land area (Million ha)	Land area (%)
Jatropha	7.12	6.3	14.93	26.2		27.33	31.0
Castor	10.43	9.2	15.91	28.0		28.46	32.3

Biofuel crop type	Ethiopia*		Kenya**			Tanzania***	
	Land area (million ha)	Land area (%)	Land area (million ha)	Land area (%)		Land area (Million ha)	Land area (%)
Croton	7.68	6.8	3.53	6.2		7.40	8.4
Cassava	11.47	10.2	6.39	11.2		22.79	25.9
Cotton Seed	1.71	1.5					
Sweet Sorghum	40.91	36.2	17.40	30.6		31.51	35.8
Sugarcane	0.70	0.62	1.26	2.2		18.96	21.5
Sunflower			8.64	15.2		17.78	20.2
Oil palm (tall)						0.66	0.75
Oil palm (compact)						0.92	1.04

(Sources : *Geremew et al., 2016 ; ** Ndegwa et al., 2011 ; ***Wiggins et al., 2011; Kassam et al., 2013)

In Kenya, the total suitable land available for production of biofuels is estimated at 48.9 million ha, which is 85% of the total land area. About 1.3 m ha (2.2%) of land in Nyanza and Western, Coast, some parts of Rift Valley and Tana River is suitable for sugarcane production. The suitable area for sweet sorghum is 17.4 mha (30.6%), and cassava is 6.4 mha (11.2%) (Muok et al, 2010; Ndegwa et al., 2011). Tanzania has very large areas of land currently little used that might be cultivated to grow biofuel feedstocks. Out of the total area of suitable land with tillage-based production of low input for cassava is 22.796mha (25.9%), and sugarcane is 18.96mha (21.5%) (Kassam et al., 2012; Wiggins et al., 2011) (Table 1). The investors who took land for liquid biofuel production in Kenya and Tanzania also terminated the investment in 2016 and 2015, respectively.

For biofuel production, the only investment is sugarcane production for sugar and its by product molasses, which can be used for bioethanol, beverage alcohol or livestock feed. There is on going research on some bioenergy crops in each country undertaken by government research institutes and universities.

3.2 Availability of edible and non-edible feedstocks for liquid biofuel production

The major feedstocks identified in Ethiopia are cassava, castor, ground nut, jatropha, maize-corn, moringa, sesame, sugarcane, sunflower, sweet sorghum and vernonia. In Kenya and Tanzania, the major feedstocks for biofuel are barley, cashew, cassava, croton, jatropha, oil palm, maize-corn, rapeseed (canola), sugarcane, sweet sorghum, and wheat.

3.2.1 Sugarcane for bioethanol production

Bioethanol is the most common type of liquid biofuel for both transport and cooking energy in eastern Africa. In this text ethanol is referring to bioethanol. Fuel ethanol is anhydrous with less than 1% water and denatured by adding 2 to 5% volume petroleum pentane plus or conventional motor gasoline. The transport sector, the growing pharmaceutical and alcohol beverage industries have demand for bioethanol. For

example, the demand for substitution of kerosene in 2014 in Ethiopia was about 85 million liters (Gaia, 2014). The major crops for the production of bioethanol are sugarcane *(Saccharum officinarum),* cassava *(Manihot esculenta Crantz)* and sweet sorghum *(Sorghum bicolour (L.) Moench*., sugar beet (*Beta vulgaris var. saccharifera* L.), and amaranth (*Amaranthus hypochondriacus* L.), among others.
There are also a number of ligno-cellulosic biomasses for bioethanol production which are different from sugarcane and sweet sorghum sugars that accumulate in the form of juice in stems.

In Ethiopia, there was blending of ethanol from 2009 to 2017 at intermittent rate of 5% (E5) and 10% (E10). Blending was practiced first from 2009 to 2015 and resumed in 2017, then later abandoned because of low production of ethanol by Metahara and Fincha sugar factories, caused by power interruption that constrained converting molasses to ethanol. E10 blending was adopted when there was better ethanol supply, while E5 was produced when supply was low.
Farmers' associations, companies and government organizations were producing biofuel crops. However, there was no private farmer that processed biofuel for consumption. For example, the out growers who have farms to produce sugarcane were providing the cane to government companies for further processing to sugar and molasses. The smallholders' sugarcane is usually used for consumption.

The molasses produced from sugar factories are used for ethanol production as power alcohol, rectified sprit, beverage alcohol, and sanitizer, in addition to yeast production and as livestock feed. However, the conversion of molasses to ethanol at the sugar factories was terminated because of internal energy shortages and damages to boilers. The ethanol factories were dependent on sugar factories for the supply of molasses, and steam of the bagasse for electricity supply. Although molasses was widely available for ethanol production, the old sugar factories and their old accessories were unable to supply sufficient steam from the bagasse and electricity to ethanol factories. Therefore, ethanol production was intermittent. The molasses was sold to liquor factories that processed them to beverage alcohol or cattle feed.

There were different NGOs working on biofuels in Ethiopia, such as Gaia association, for use as cooking fuel by supplying to poor people and refugees. Gaia association purchased ethanol or processed molasses to ethanol to supply to firewood carriers to trade around Addis Ababa, and this kept them away from trading in firewood. About 20,000 to 25,000 liters of ethanol was supplied to such firewood traders as a means to reduce deforestation. Gaia association together with the Former Women Fuelwood Carriers Association (FWFCA) established a 1,000 liter/day community owned ethanol micro distillery (EMD). The EMD was based on molasses to substitute firewood, charcoal and kerosene. In the EMD different problems arose including lack of waste disposal sites, power shortages and lack of molasses and then finally the equipment was damaged and dismantled by the local people. Later, the feasibility of establishing small scale distillers was questioned, and the recommendation was to have distillers producing over 10,000liter per day accompanied with 4kg of molasses for a liter of ethanol.

The expansion of sugarcane to produce biofuels has been observed at 13 sugar factories in Ethiopia, 16 sugar factories in Kenya, and five sugar factories in Tanzania. Eastern Africa countries have been producing sugar since 1992 in Kenya, 1933 in Tanzania and 1954/55 in Ethiopia. The ethanol producers are two in Ethiopia (Metahara & Fincha), two in Kenya (Mumias sugar factory and Kibos Sugar &Allied); and one in Tanzania (Kilombero Sugar Company Limited) (Table 2). Although the main target for sugar companies is to produce sugar, they sell molasses to ethanol distillers or process to other products, depending on market demand, such as ethanol fuel, sanitizers, beverage alcohol, and cattle feed.

Respondents from the Ministry of Energy in Kenya stated that the first ethanol plant was set up in 1977 in Kisumu but only operated for two years. In 1983, ethanol blending program was reintroduced, but collapsed in 1993 because of the uneconomical way of producing and transporting bioethanol to the market, drop in global oil prices, and demand for other uses such as in the beverage alcohol sector and lack of favourable policy and regulatory frameworks. In Tanzania, only Kilombero Sugar Company Limited was producing bioethanol, and the remaining ones are expected to produce ethanol in 2022/23.

For the eastern Africa region, the most common feedstock for the production of ethanol is molasses from sugarcane although additional sweet sorghum and cassava are common in Kenya and Tanzania. Production of bioethanol from sweet sorghum enhances food security because with every harvest of sweet sorghum, stalks are used for ethanol production and sorghum seeds for human consumption. Bioethanol from sweet sorghum is the most profitable with a gross margin of over US$707.5USD per hectare in Februrary 2020 in Kenya.

Table 2. Sugar factories potential production of ethanol

Country	No	Sugar factory (Project) Name	Productive area (ha)	Year started or year to start	Amount of molasses produced (Ton/yr.) (NCC*0.04)	Amount of ethanol produced in 2018/19 (Litrs/yr)	Potential capacity of ethanol (Litrs/day)	Potential capacity of ethanol (Litrs/yr)	Remark on ethanol producers and production date
Ethiopia	1	Metahara	10,222	1970	169.6	12,500,000	43,248	10,812,000	Produced ethanol in 2021.
	2	Fincha	19,000	1998	768	11,754,498	195,840	48,960,000	Produced ethanol in 2021.
	3	Wonji/ Shoa	12,800	1954	400		102,000	25,500,000	Private and government share in 2022
	4	Kuraz 1	141,014	2019	384		97,920	24,480,000	Potential to commence in 2023
	5	Kuraz 2		2019	384		97,920	24,480,000	Private company to produce ethanol in 2022
	6	Kuraz 3		2019	384		97,920	24,480,000	Potential to commence in 2023
	7	Kuraz 5		2019	768		195,840	48,960,000	Potential to commence in 2023
	8	Wolkayit	35,101	2020	768		195,840	48,960,000	Potential to commence in 2023
	9	Tana Beles 1	35,073	2020	384		97,920	24,480,000	Potential to commence in 2023
	10	Tana Beles 2		2020	384		97,920	24,480,000	Potential to commence in 2023
	11	Tendaho 1	43,478	2015	416		106,080	26,520,000	Potential to commence in 2023
	12	Arjo Didesa	4,000	2018	256		65,280	16,320,000	Potential to commence in 2023
	13	Kesem	6,507	2020	192		48,960	12,240,000	Private ethanol company construction in 2022
	Total		307,195		5,657.60	24,254,498	1,442,688	360,672,000	

Country	No	Sugar factory (Project) Name	Productive area (ha)	Year started or year to start	Amount of molasses produced (Ton/yr.) (NCC*0.04)	Amount of ethanol produced in 2018/19 (Litrs/yr)	Potential capacity of ethanol (Litrs/day)	Potential capacity of ethanol (Litrs/yr)	Remark on ethanol producers and production date
Kenya	1	Miwani Sugar Company	1,900.00	1922	73.6		18,768	4,692,000	Public owned but under receivership
	2	Muhoroni Sugar Company	13775	1964	88		22,440	5,610,000	Public, closed and will start in 2022
	3	Chemelil Sugar Company	18,186.00	1965	96		24,480	6,120,000	Public under receivership
	4	Mumias sugar factory	198	1973	288	4,500,000	73,440	18,360,000	Public, milling
	5	Nzoia Sugar Factory	18,775.00	1978	96		24,480	6,120,000	Public, milling
	6	South Nyanza Sugar Factory	8,959.00	1979	96		24,480	6,120,000	Public, milling
	7	West Kenya Sugar Company, Kaka.	48,011.00	1981	208		53,040	13,260,000	Private milling
	8	Soin Sugar Factory	1,915.00	2006	9.6		2,448	612,000	Private milling
	9	Kibos Sugar &Allied Industries	7,393.00	2007	112	3,750,000	28,560	7,140,000	Private milling
	10	Kwale International Sugar Company Limited (KISCOL)	6,763.00	2007	96		24,480	6,120,000	Private milling
	11	Butali Sugar Mills	19,749.00	2005	80		20,400	5,100,000	Private milling
	12	Transmara Sugar company	15,308.00	2011	128		32,640	8,160,000	Private milling
	13	Sukari Industries Limited	17,710.00	2011	96		24,480	6,120,000	Private milling

Country	No	Sugar factory (Project) Name	Productive area (ha)	Year started or year to start	Amount of molasses produced (Ton/yr.) (NCC*0.04)	Amount of ethanol produced in 2018/19 (Litrs/yr)	Potential capacity of ethanol (Litrs/day)	Potential capacity of ethanol (Litrs/yr)	Remark on ethanol producers and production date
	14	Busia Sugar company	12,858.00	2008	96		24,480	6,120,000	Private milling
	15	West Kenya Sugar Company, Olepito	9,013.00	2017	40		10,200	2,550,000	Private milling
	16	West Kenya Sugar Company, Naitri	5,000.00	2020	80		20,400	5,100,000	Private milling
		Total	205,513.00		1,683.20	8,250,000.00	429,216	107,304,000	
Tanzania	1	Kilombero Sugar Company Limited	25,000	1964/1988	142.08	1,400,000.00	36,230	9,057,600	Produced ethanol in 2021
	2	Tanganyika Planting Company L.	8,000	1973	60		15,300	3,825,000	No ethanol in 2021
	3	Kagera Sugar Limited	9,000	1933/1974	56		14,280	3,570,000	No ethanol in 2021
	4	Mtibwa Sugar EstatesLimited	6,000	1958	72		18,360	4,590,000	No ethanol in 2021
	5	Bagamoyo Sugar Ltd Tanzania	10,000	2022	72		18,360	4,590,000	will produce ethanol in 2022
		Total			402	1,400,000.00	102,530	25,632,600	

(Source: Authors interview of sugar companies)

The production of ethanol from molasses depends on the installation of ethanol distillers and the productivity of sugarcane farm. All the sugar factories in Ethiopia were state owned and all the cane is produced by the state except in one of the factories called Wonji Sugar Factory where local farmers participate as out-growers. Most of the factories in Kenya are privatized or in the process of privatization and most of the factories in Tanzania are in transition to private sector during the data collection period. In Ethiopia, there are more than nine varieties of sugarcane under cultivation, all of which mature in 16-18 months. The planting and harvesting season in western Ethiopia, for example in Fincha sugar factory is usually from mid-October to mid-June, with elevation between 1350 and 1600 m.a.s.l, average annual precipitation of 1309 mm and average maximum and minimum temperatures of 31.5˚C and 14.6°C, respectively. The processing of sugar and ethanol production is done inside the crop production areas. The production days range from 209 to 257 days per year with average of 250days. The productivity of sugarcane is about 80 to 192 tons in a hectare with an overall average of 138 tons per hectare. The production of ethanol in Ethiopia in the year 2008/09 to 2019/20 ranged from 5,879 to 14,228 kiloliters depending on the availability of power supply in the fermentation and distillation plants and in the production of molasses.

The consumers of the bioethanol are national government companies for fuel stations blending (99.9% alcohol with 0.1% water), for cook stove energy production (96% alcohol with 4% water), and private companies for consumption of beverage alcohol (48 to 70% alcohol with 30 to 52% water). The sugar and ethanol production are said to be a lucrative business because a number of products are obtained from sugarcane processing (Fava Nevesa and Chaddad, 2012).

In Ethiopia, Kenya andTanzania, the sugar factories producing ethanol are those that installed molasses fermenters and ethanol distilleries, which were only one or two in each country. As a result, the current, 2020/2021 bioethanol production was 24.25 million liters in Ethiopia, 8.25 million liters in Kenya and 1.4million liters in Tanzania. Improvements in productivity and technology are expected to increase bioethanol production. The improvement in productivity is increasing the yield to reach an average of 138 tons of sugarcane or more per hectare. The improvements in technology contribute to reducing wastage in molasses and in ethanol production, as well as increasing power supply to ethanol distillers, making it possible to convert all the molasses produced to ethanol. At the existing technological conditions, the Ethiopian 13 sugarcane factories can produce 432.41 million liters of ethanol per year, while the Kenyan 16 factories can produce 289.28 million and those Tanzanian five factories can produce 81.64 million liters per year: with average of 250 working days (Table 3). However, it was observed that the factories were not producing bioethanol based on all the molasses produced because of the weak capacity of old distillers and interrupted power supply.

Table 3. Sugarcane molasses ethanol production in existing and improved technologies

Country	Area of sugarcane (thousand ha)	Existing technology of ethanol production		Improved technology and productivity of
		Current production (million litres/year)	Potential production (million litres/year)	Ethanol production (million litres/year)
Ethiopia	307.196	24.25	360.672	432.41
Kenya	205.513	8.25	107.304	289.28
Tanzania	58.000	1.4	25.633	81.64

(Source: Authors analysis of sugarcane land area-based data)

Assumptions in conversion of biomass to ethanol	
1 tone of sugarcane	0.7 tone juice
1 tone of sugarcane	0.04 tone molasses.
1 tone of molasses	255 liters bioethanol
1 year working days	250 days

(Fava Nevesa Chaddad, 2012 and authors interview in Ethiopian sugarcane factory)

3.2.2 Ligno-cellulosic biomass for liquid biofuel production

The feedstock cost is the largest contributor to the production costs of conventional liquid biofuels. Further, the cost of conventional biofuels from food-based feedstocks is very sensitive to changes in the prices of the feedstocks used. In ethanol production, feedstock costs can be accounted to 60 to 85% of the total production cost because of labor, food, and transport costs (IRENA, 2013). In biodiesel the production cost is even more pronounced, with feedstock costs making up 80 to 90% of production costs. The profitability of liquid biofuel production is therefore very much dependent on the cost of feedstock. The global market prices for these raw materials face significant variations due to changes in demand and supply of both food and fuel. Therefore, production costs for ethanol via the enzymatic hydrolysis of residual lignocellulosic biomass such as agricultural residues, municipal solid wastes and sugarcane bagasse may be lower than production based on feedstocks that could also be used for food or feed production.

Many of the sugar factories recommend improving the profitability of the sugarcane industries. It was suggested that depending on environment and economy it could be advisable to explore other cheaper and more price stable biomass sources for production of liquid biofuels.

Biomass-derived ethanol has the potential to be an environmentally friendly transport fuel and a key alternative to fossil gasoline. Cellulosic ethanol is produced from lignocellulose by using different techniques including hydrolysis (i.e., concentrated acid, diluted acid, or enzymes) of the cellulose to monomer sugars. Acid hydrolysis has been used since a century ago, while enzymatic approaches are recently utilized. Lignocellulosic biomass are attractive feedstocks for bioethanol production because they are diverse, abundant and less costly; they include residues of first-generation crops, forest biomass, high yielding energy crops, and municipal wastes. However, these bioethanol production systems are presently at a relatively early stage of production and accompanied with a number of pilot and demonstration second generation bioethanol plants that hold potential for widespread commercial implementation.

There are about 2.2million tons of agricultural residues in Kenya, and 19.7million tons in Ethiopia, as well as 24.2million tons of woody biomass residues in Kenya and 105.2million tons in Ethiopia; 3.02kilotons of sugarcane bagasse in Tanzania and 387.7 kilotons in Ethiopia (Table 4), all of which could be used for lignocellulosic bioethanol production. For example, one ton of dry woody biomass produces approximately 89.5 galons or 339 litres of cellulosic ethanol (BRDB, 2008). If there is adequate technological development to produce ethanol from lignocellulosic biomass, as well as measures to use all the sugarcane bagasse processing, the total bioethanol production could reach 8.2 billion litres/year in Kenya, 10.8billion in Tanzania and 35.6billion litres/year in Ethiopia, which is higher than their imports of petroleum. Lignocellulosic biomass is therefore, an additional potentially attractive feedstock for the production of ethanol in the eastern Africa countries.

Table 4. The potential of bioethanol production from lignocellulosic biomass

Sources	Ethiopia	Kenya	Tanzania
Agricultural residues (million tons/year)	19.70	2.20	2.30
Woody biomass residues (million tons/year)	105.20	24.20	31.90
Sugarcane bagasse (kilo tons/year)	387.70	13.72	3.02
Ethanol from agricultural residues (million litres /year)	6.78	0.76	0.79
Ethanol from woody biomass residues (million litres /year)	35,590.21	8,187.10	10,792.09
Ethanol from sugarcane bagasse (kilo litres /year)	110.11	3.90	0.86
Imports of petroleum and its products (billion litres)	4.5 in 2019	6.1 in 2018	3.6 in 2020
Total potential of ethanol (billion litres /year)	35.597	8.188	10.793

(Source: Authors analysis of review and field data)

Assumptions in conversion of biomass to ethanol	
1 tone of wheat straw	0.294 litre bioethanol*
1 tone of rice straw	0.28 litre bioethanol*
1 tone of corn straw	0.458 litre bioethanol*
1 tone of sugarcane bagasse	0.284 litre bioethanol*
1 tone of dry woody biomass	89.5 gal (338.31 litres) of cellulosic ethanol**
1 tone of sugarcane	0.3 tone bagasse
1 year working days	250 days

(Source : *Sarkar et al. 2012 ; ** BRDB, 2008)

Ethiopia imported nearly 4.5 billion litres of liquid fossil fuel including gasoline, jet fuel, kerosene, gasoil, and others; and spent US$2.82 billion USD during the fiscal year concluded in July 2019. The import of petroleum in Ethiopia accounts 40% of total imports and absorbs more than 60% of export earnings (MME, 2007). The production of liquid biofuel from lignocellulosic biomass at 35.6 billion litres/year is about eight times the fossil fuel imported. Then the liquid biofuel can be used as blend or pure substitute of the imported fossil fuel and create additional income by exporting the extra liquid biofuel.

Kenya imports all of its petroleum products, and spending about 40% of its foreign exchange earnings on importing refined oil and other petroleum products. Kenya imported and consumed about 6.1 billion litres of petroleum products in 2018 (KNBS, and EPRA, 2019). The use of lignocellulosic biomass could produce 2.2billion liters of bioethanol and reduce this import bill.

Tanzania has been importing liquid biofuel and consumed about 3.6 billion litres of petroleum products in 2020 (Faria, 2021); however, the country has capacity to produce about 10.8 billion litres of ethanol from lignocellulosic biomass.

3.2.3 Pyrolysis oil production

Pyrolysis oil or bio-oil is another liquid biofuel, a potential alternative to petroleum-based fuel. It is produced from pyrolysis or heating (400-1000°C) of biomass in oxygen limited furnace or kiln. Different types of biomasses produce varying yields of pyrolysis oil. Some of the potential feedstocks for bio-oil production are bagasse; hardwood and softwood; municipal, livestock and wood waste; potato skin, wood sawdust, waste furniture sawdust, rice husks, corn cobs, and corn stovers.

Other potential pyrolysis oil producing biomass includes wood of *eucalyptus* species, invasive species biomass, and agricultural residues. The latter are estimated at 19.7mtones/yr. in Ethiopia, 2.2mtones/yr. in Kenya and 2.3mtones/yr. in Tanzania (Table 5).

Table 5. Potential feedstock for pyrolysis oil in Ethiopia, Kenya and Tanzania

Biomass type	Ethiopia*	Kenya**	Tanzania***	Characteristics	Type of product
Eucalyptus wood	1 million ha in 2021	~350,000 ha in 2021	25,000 ha in 2016	fast growing and easily propagated	for pellet and pyrolysis bio-oil
Acacia woodland species	$100km^2$ (minimum) in 2021			occupied grazing land	for pellet and pyrolysis bio-oil
Prosopis invasive species	1 million ha in 2011	37 million ha in 2021		fast growing and occupied grazing land	for pellet and pyrolysis bio-oil
Lowland bamboo	469,664 ha	133,273 ha	127,000 ha	fast growing	charcoal briquettes and pyrolysis bio-oil

Biomass type	Ethiopia*	Kenya**	Tanzania***	Characteristics	Type of product
Coffee residues	214,299 tonnes/year	38,620 MT/year in 2017	80,307t/year	fast accumulation	for biogas, compost etc., and for pyrolysis bio-oil
Cotton stalk residue	potential 400,301.5 tonnes · yield, 89,000 tonnes /year	47,400 MT/year in 2017	512510t/year		for briquette and pyrolysis bio-oil
Chat (cash crop)	yield 6,608 tonnes/ year (826 charcoal tonnes/year				for charcoal and pyrolysis bio-oil
Sawmill residue	25,000 tonnes /year	6,120,000 m^3/year in 2010	205,400 tonnes/year in 2013		for pellet and pyrolysis bio-oil

(Source: *MoWE, 2012; **Republic of Kenya, 2002; ***MNRT, 2013)

3.2.4 Biofuel production and circular bioeconomy

A circular economy is one that focuses on the technological and organizational innovations aimed at accounting for and reducing resource use and consumption, improving resource use efficiency, and recycling, and minimizing waste and the emissions of greenhouses gases (GHG). A bioeconomy emphasizes the importance of technological innovations aimed at complementing or substituting non-renewable resources with bio-based alternatives. The circular bioeconomy is the combination of these two concepts focused on reducing the use of resources and waste produced during the production cycle.

The production of liquid biofuels contributes to the building up of a circular bioeconomy if such fuels are produced technically by:

(a) Collecting available residues from food crops and forest products (forest harvesting wastes, organic wastes, wastes from households and restaurants, discarded wood products such as paper, construction, and demolition wood waste, and waste waters). These residues can be used partly for soil amelioration, while 25-50% can be used for livestock feed and for liquid biofuel production. The agricultural residues can have an energy content of 15 gigajoules (GJ) per ton. As food production grows for the growing population, the projected agricultural residues for bioenergy will also grow (FAO, 2015).

(b) Planting bioenergy crops on land freed up by reduced waste and losses in the food chain (annual cereals, oil- and sugar crops).

(c) Planting high-yielding trees and grasses (perennial plants like switch grass, miscanthus and tree plantations like willow, poplar, eucalyptus, pine etc.) on land made available through intensive cultivation of farmland to get excess yield. It has been estimated that 30% of the volume of wood extracted are logging residues, 50% residues are obtained in production of sawn wood and wood panels, and 10% is obtained in production of wood chips. Therefore, trees in forest land could provide residues for liquid biofuel (FAO, 2015). As shown in Table 3, there are ample biomass resources in eastern Africa that can produce ethanol through saccharification, or biodiesel, pyrolysis oil and syngas through pyrolysis of eucalyptus wood.

In Africa, the main bioenergy sources are the traditional firewood. The main challenge is to move away from the traditional bioenergy towards modern bioenergy that incorporate liquid biofuels (GBEP, 2011). The first-generation biofuels are obtained from forest or agricultural crops such as jatropha, sweet sorghum, oil palm. Then the transition from first generation to second generation biofuel production i.e., using lignocellulosic biomass (agricultural residues, wood residues, firewood and straw) for liquid biofuel (bioethanol and biodiesel) are examples of activities in a circular green economy and they are possible measures to avoid competition on agricultural food crops or forest land.

3.2.5 Biodiesel production

Field observations and interviews made on stakeholders revealed that the demand for vegetable oil for food is very high. Therefore, it could be expensive to use oils from edible seeds and vegetables in eastern Africa for liquid biofuel production given that these feedstocks are more important for food security in the region. It was also noted that there was no viable production and processing of biodiesel in Ethiopia, Kenya, and Tanzania. However, there were some seedling planting and machinery installation activities in different parts of the countries mainly for non-edible oils like jatropha and castor oil.

Some experiences from Ethiopia

According to information obtained from Ethiopian Investment Agency, about 20 local and foreign investors had requested investment licenses to produce biodiesel in 2007. Nine of the investors received licenses, with only one having started implementation. The licensing took long and was not well coordinated. In 2016, none were operational except one Indian investor (S&P Energy Solutions Plc.) in Benishangul Gumz Regional State which had been planting pongamia seedlings on 50,000 ha since 2009. In Feb. 2021, when this data was collected, there was no investment on biodiesel production, and all had either stopped the biofuel investments in 2016 or changed to other type of investment.

For biodiesel production jatropha (*Jatropha curcas L.),* castor *(Ricinus communis L.),* cotton seed *(Gossypium hirsutum L.* and *Gossypium herbaceum L.),* and croton *(Croton megalocarpus Hutch.)*, oil palm, Millittia species, soyabean, sunflower, *Trichilia sp* and others can easily be grown.

The most used feedstock to produce biodiesel was jatropha. In sampled sites in Ethiopia, castor and ground nut are common in Harar-Fedis, sugarcane in Wondo Genet, moringa in Sawula (Southern Ethiopia), jatropha in Bati and sesame and oil palm in Gambella.

Since jatropha was the most promising crop for biodiesel in eastern Africa, area occupied in Ethiopia and Tanzania was 200ha and 17,600ha in 2008 that increased to 125,000ha and 168,000ha in 2015, respectively. In Ethiopia, seed production was commenced, oil extracted, biodiesel and soap manufactured at laboratory trial scale. The initial fund to plant cuttings and seedlings of jatropha was obtained from national project fund, however, the whole activity terminated when the project phased out. The production of biodiesel was not significant and terminated soon (Global Market, 2008). The lack of finances, unattractive market, and poor technical capacity of the biodiesel production project in Ethiopia led to the termination of the oil, soap and biodiesel production and farmers frustration. What remains is the degraded land that has been rehabilitated (Figure 2).

Figure 2: Rehabilitated jatropha planted degraded land in Bati woreda, Ethiopia (Source: Authors)

There were different types of research activities underway on biofuels in different countries of eastern Africa. In Ethiopia, Wondo Genet Agricultural Research Center in collaboration with Melkasa and Werer Agricultural Research Center of the Ethiopian Institute of Agricultural Research were conducting research on castor, *jatropha, vernonia, croton*, sweet sorghum, oil palm, elephant grass, sugarcane, and algae.

There were different administrative and financial constraints in biofuel research organization. For example, the biofuel research was not well organized and had no proper coordination and ownership; some biofuel research activities were attached to different departments and centers/institutions such as medicinal and aromatic plant research, and also research was sometimes simply conducted at project level under selected crops like jatropha, castor, vernonia and amaranths, and sweet sorghum in

Werer Agricultural Research Center and Wondo Genet Agricultural Research Center although there were researchers assigned to conduct research.

From all these experiences, the following were observed as the major problems in biofuel development in Ethiopia:

- Lack of or inadequate technology: old technologies were used to process biofuel feedstock to produce ethanol and oil but did not function as needed.
- Lack of high yielding variety feedstock crops: the potential biofuel crops were not researched, and no breeding effort made. For example, the yield obtained was very low, as low as 4 kg / tree of jatropha seed that resulted into 1liter oil.
- Improper site selections as potential suitable areas for biofuel crop production,
- Lack of or inadequate awareness creation to consumers on the potential of bioenergy crops.
- Inability to afford, access and use of liquid biofuel without subsidies for rural households since the first-generation biofuel production was not profitable.

Some actions taken and to be taken to contain these problems:

- ➢ A strategic document on the production and processing of liquid biofuel was prepared by Southern Nations and Nationalities People Region (SNNPR),
- ➢ Biofuel sector of Ethiopia was coordinated at Federal Ministry of Energy at directorate level,
- ➢ Federal Level Round Table for Sustainable Biofuel Production (RTSBP) strategy was developed to produce airplane liquid biofuel,
- ➢ A recommendation for the establishment of a liquid biofuel agency in regions, zones and districts based on the model of an existing and functional biogas agency,
- ➢ Sustainable liquid biofuel production can be done through the coordination of different sectors of Ministry of Water, Irrigation and Energy (MoWIE), and Ministry of Agriculture with respect to different technological aspects and agronomic practices with proper feedback to each other. Proper follow up and interface in productivity, marketing and quality assurance management are highly required.

Some experiences from Kenya

In Kenya, several biofuel activities were sparked by the convening of the Kenya National Biofuels Committee in 2007 by the Ministry of Energy. This led to the biodiesel policy strategy in 2008, revised in 2010 to promote production and use of biodiesel. It also led to the establishment of the Kenyan Biodiesel Association (KBDA). According to respondents in the Ministry of Energy in Kenya, the potential feedstocks for production of biodiesel are jatropha, castor (*Ricinus communis),* croton (*Croton megalocarpus*) and Canola (*Brassica napus)*. However, little data exists on their cultivation and management because the crops have been found growing scattered. The last project terminated in 2016.

Some experiences from Tanzania

In Tanzania, jatropha was widely planted for the purpose of producing biodiesel. However, currently there is no production of biodiesel. In the visited biodiesel producing areas, it was confirmed that the production of biodiesel has ceased. The earlier production that was project based depended on donor funding, so when the projects phased out the production also terminated. The current study recorded the last project closed in 2015.

During the current study, no production of biofuel was recorded from palm oil, though the plantation for production of palms oil is available. In Tanzania, there have been efforts made in planting the palm trees (Figure 3) to increase the production of cooking oil and thus scaling down the importation of this oil. The domestic production constitutes less than 2% of the country's consumption.

Figure 3: Oil palm farm in Tanzania (left) and Kenya (right)
(Source: Authors)

3.2.5.1 Microalgae production

Microalgae oil has been identified as a potential biodiesel feedstock. Microalgae are promising third generation liquid biofuel feedstock due to their rapid growth rate, carbon dioxide fixation ability and high lipid production capacity; in addition to without competing with food cropland. Ethiopia, Kenya, and Tanzania, being tropical countries, have intense sunlight which is ideal for microalgae cultivation (Abraham et al., 2013). The necessary conditions for microalgae development are linked to favorable climatic conditions, availability of sunlight throughout the year, optimum temperature, relative humidity, precipitation and evaporation, land topography and access to nutrients, carbon sources and water (Maxwell et al., 1985).

Commonly known microalgae in Ethiopia are *Anabaena, Botryococcus braunii, Chlorella, Chroococcus, Gloeocapsa, Haematococcus pluvialis, Lyngbya, Oedogonium sp., Oscillatoria, Scenedesmus, Synechoccystis, Spirulina* and *Synedra,* etc., which may contain up to 75 % lipids; making them very suitable to produce biodiesel (Spoiler et al., 2006; Chisti, 2007).
Research conducted at Metahara Sugar Factory in eastern Ethiopia, revealed that microalgae processing produced biodiesel, upgraded biogas, and bio-fertilizer at 188 tons/year, 1,974,882 m^3/year and 42 tons/year, respectively. Also, the research showed that sugarcane factory wastes, and by-products have a significant potential for viable biofuel production from microalgae (Zewdie and Ali, 2020). Therefore, microalgae production can be integrated to sugar factories that produce bioethanol.

Some microalgae strains can generate 70% weight by weight (w/w) lipids in their biomass. The maximum microalgae lipid yields in Kenya and Tanzania are 2.47 m^3/ha, i.e., 15.6g/m^2 perday, and they commonly double in size every 3 to 24 hours (Spolaore et al., 2006). Microalgae grow all times throughout the year and can be harvested many times a year. This creates the possibility for microalgae to produce 11,238litres biodiesel per hectare per year, which is higher than the 150litres biodiesel from a hectare of jatropha and higher than the 700 liters of ethanol in a hectare of sugarcane plantation.

3.2.6 Greenhouse gas emission reduction potential of liquid biofuel

With the aim of net zero emission in the use of ethanol for cooking at household level reduces emissions that can be created by solid biomass fuel combustion. It reduces 99.8% of particulate matter created by burning solid biomass in three stone stoves and 91.0% of that created by wood/charcoal Rocket Combo stoves. The use of ethanol as cooking fuel also reduces 95.1% of carbon monoxide created by charcoal stoves (Table 6).

Table 6. Emission reduction of ethanol clean cook stove over other stoves

Characteristics	Three stone fire	StoveTec Rocket	Charcoal Jiko	Wood/Charcoal Rocket Combo
Reduction in particulate matter	99.8%	99.5%	98.4%	91.0%
Reduction in carbon monoxide	93.4%	75.0%	95.1%	87.9%
Improved efficiency	3 times	2 times	2.8 times	1.8 times

(Source: MacCarty et al., 2010)

Previous studies reported that bioethanol stoves improve efficiency by 1.8 to 3 times when compared with using wood in three stone fire stoves: StoveTec Rocket, charcoal Jiko, and wood/ charcoal Rocket Combo (Gaia Association, 2014) (Table 6). Using biodiesel also reduces end use emission by 38.90 to 39.42% when compared with firewood and kerosene at household level (Fekadu et al., 2019).

On the other hand, deforestation of land for biofuel production creates emission of greenhouse gases. However, the continuous production of liquid biofuel in the place of wood fuel could reduce emissions because of the substitution of fossil fuel for transport and energy, the production of the fuel from residues, wastes, and sugar or oil containing parts. For example, biodiesel, seed cake and seed oil can reduce GHG through the replacement of diesel fossil fuel. In Ethiopia, approximately 63,000 hectares of land is covered by jatropha. Then based on an assumption of GHG reduction of 100 tha^{-1} over 10 years (10 $tha^{-1}yr^{-1}$), jatropha in Ethiopia can reduce 3.15 tons GHG, based on the proper accounting of vegetation's live period of at least five years (EMoMPNG, 2018). The use of corn and switch grass as sources of biofuels can reduce the greenhouse gas emissions by 29 to 396 g of CO_2 equivalent per mega joule of ethanol per year (Schmer et al., 2014). The conversion of CH_4 to CO_2 by reducing the rate of decomposition reduces emission.

Biodiesel and bioethanol production have a great role in reduction of GHGs and shifting towards clean energy. In the Ethiopian climate resilient green economy strategy (CRGE), the transport sector has green growth initiatives that include changing the fuel mix by adding biodiesel to the diesel mixture, increasing the amount of ethanol in the gasoline mixture, and promoting the adoption of hybrid and plug-in electric vehicles to get a combined abatement potential of nearly 1.0 Mt CO_2^e (CRGE, 2011).

The blending of biodiesel as B5 (5% biodiesel) into the national diesel fuel mixture has an abatement potential of 0.7 Mt $CO2^e$ in 2030. The blending of bioethanol as E15 (15% bioethanol) nationally has an abatement potential of 0.2 Mt $CO2^e$ in 2030 in Ethiopia. The achievement of the abatement potential requires about 486,000 hectares of arable land to produce biodiesel and 25,000 hectares of arable land for bioethanol (CRGE, 2011) if first generation bioenergy crops are utilized or the already available lignocellulosic biomass is sufficient if second generation biofuel technologies are employed.

Moreover, the emission from the transport sector in Ethiopia was around 4.5 $MtCO_2^e$ in 2010, 9.8 $MtCO_2^e$ in 2014 and 12.24 $MtCO_2^e$ by 2016; with 75% of that originating from road transport, freight and construction vehicles, and passenger vehicles. Road transport accounted for the major mode with about 66%, followed by off-road. Most of the GHG emissions in the country originate from the capital city, Addis Ababa, with about 8.51 Mt CO_2^e in 2016 and accounted for 73 % of the total road transport emission. Liquid biofuel blending can reduce GHG in transport sector. For example, ethanol 10% blending in Addis Ababa, Ethiopia, can reduce 20% GHG emissions; and blending at the country level can reduce 30% GHG emissions.

In Bati woreda of northern Ethiopia, jatropha plantation as live fence stores 137.36 $tCha^{-1}$ while on degraded lands it is about 5.41$tCha^{-1}$, totalling 142.77$tCha^{-1}$. This showed greater amount of carbon storage as live fence, which is mostly practiced in Ethiopia (Teshome et al., 2013). However, there is no biodiesel production at the country level that indicated the level of emission. The frequently practiced bioethanol production can indicate the level of emission at the farm level depending on the agrochemicals and the total bioethanol produced. That is sugar factories were using chemical fertilizers like UREA and NPS (nitrogen, phosphorus, sulphur) for soil enrichment, herbicides, and fungicides to protect disease and insect pests. The highest emission sugarcane ethanol production occurs during cultivation of cane about 190 gCO_2^e/liter of bioethanol (Table 7).

Table 7. GHG emissions based on Life Cycle Analysis (LCA) of sugarcane to bioethanol

Stage in life cycle	Unit of measurement
Sugarcane cultivation	190 gCO_2^e/L of bioethanol
Nitrogen (N_2) fertilizer – 52% of cane emissions	98.8 gCO_2^e/L of bioethanol
Cane milling for bioethanol production	9.19gCO_2e/L of bioethanol
Net GHG emissions are 270.87 $gCO_2^{e/}$L of bioethanol for complete life cycle chain. Nitrogen (N_2) fertilizer contributing ~37% of total emissions	
Stage in life cycle	Emissions (%)
Cultivation	70
Milling/Ethanol production	4
Transportation	8
Co-generation by bagasse combustion	18

(Source: International Center of Research in Agroforestry (ICRAF)/ Roadmap)

Further, sugarcane harvesting is done by burning the leaves (Figure 4) and residues which also emit different levels of GHG. The application of decomposed organic bagasse residues, chemicals and fertilisers increase GHG emission from soil. For example, application of urea increases emissions of CO_2 and N_2O from soil (Serrano-Silva et al., 2011). However, there are different by products like bagasse in sugar production, vinasse, and other organic wastes in ethanol production, which can be converted to biogas to get organic fertilizer and therefore, reduce emissions. The production of biogas (methane) can be a source of clean energy and organic fertilizer (bio-slurry) to ameliorate soil, altogether used to reduce emissions.

Figure 4: Sugarcane farm at maturity stage, harvesting and transport from left to right (Sources: (a) Author from Ethiopia; (b) Ndegwa et al., 2011 from Kenya; (c) and (d) Author from Ethiopia)

It is generally believed that biofuels made from grain crops produce as much carbon emissions as fossil fuels in cases deforestation was done to give way to the grain crops feedstocks (Fargione et al., 2008). Biofuels produced from crop residues or waste, on the other hand, tend to reduce carbon emissions. Producing ethanol from lignocellulosic biomass has low life cycle GHG emissions that range from 16 g CO_2^e/

MJ for straw to 10 g CO_2^e/ MJ for sawdust-based ethanol production (EU, 2018; St1, 2019). Direct emissions from biofuel are lower than those of fossil fuels; burning one megajoule of energy gives 39g of CO_2^e, whereas fossil fuels emit 75.1g of CO_2^e.

Kenya's total GHG emissions are estimated at 60.2 $MtCO_2^e$, mainly from Agriculture and Land Use and Land Use Change and Forestry activities (LULUCF). LUCF sector activities removed 31.2 $MtCO_2^e$ in 2013, which represents a substantial carbon sink. Kenya commits to reduce GHG emissions by 30% (143 $MtCO_2^e$) relative to business-as-usual levels by 2030. Mitigation actions include expansion of renewable energy technologies; enhancement of clean energy technologies with abatement potential of 1.64 $MtCO_2^e$; adoption of low carbon and efficient transport including using biodiesel with abatement potential of 1.2 $MtCO_2^e$ and improved waste management (KNBS and EPRA, 2019).

Tanzania commits to reduce greenhouse gas emissions economy-wide between 30-35% relative to the Business-As-Usual (BAU) scenario by 2030 (i.e., 138 - 153 $MtCO_2^e$) by promoting clean technologies for power generation, and use of diverse renewable sources such as geothermal, wind, hydro, solar and bioenergy in energy sector (URT, 2021).

3.3 Opportunities, challenges and prospects in the production and use of liquid biofuels

Development of liquid biofuel systems creates income opportunities for farmers by diversifying crops for both food and biofuel production, creates investments in infrastructure like roads, offers prospects of energy security, can reduce pressure on forests for wood fuel, and reduce dependency on oil imports (UN, 2007) (Table 8). The other prospects are development of local industries, provision of alternative energy for rural mechanization, foreign exchange earnings from exports, import substitution of fossil fuels; and long-term financial, social and environmental sustainability. The availability of suitable land, water, cheap labour, suitable climate for growing many of bio-energy crops in the eastern Africa region are opportunities. Moreover, the global warming due to climate change that requires a shift to bioenergy to reduce GHG emissions requires producing liquid biofuels. Existence of national and international legislations and commitments to guide production of feedstocks and use in ways that ensure safety to the environment and consumers, are ways through which these opportunities could be promoted.

However, there are some challenges; for example, while pastoralist areas were prioritized for jatropha, facts on ground have shown that these areas are not suitable for producing jatropha due to their arid nature. The lack of plans and financial resources for processing of jatropha seeds to oil and biodiesel resulted in damping about 50 tons of seeds in Bati district of Ethiopia (Figure 5), and constraining development of the liquid biofuel industry in the region based on jatropha feedstock. Also, there is lack of accurate and sufficient data on biofuel crops; in addition to general institutional, market, economic, social, technical, legal challenges that constrain the development of this industry in the region. Further, lack of incentives in biofuel development and utilization**,** internal company problems, and lack of monitoring and evaluation of project activities, weak policies, and weak institutional capacities, are some additional constraints (Table 9 and 10)

Table 8. Opportunities and prospects in liquid biofuel production

Opportunities	Prospects
• Creating employment	• Development of local industries, Enhancing on job training of locals
• Diversifying income sources	• Access to energy and to rural mechanization
• Creating demand and new markets for liquid biofuel	• Earning foreign currency, • Reducing GHG,
• Creating production facilities like factories	• Initiating local uses of biofuels, • Growing the economy of the country
• Training locally available labour force	• Creating local energy sources
• Long time shelf life of liquid biofuel for transport sector	• Expertise development in biofuel production, Local breeding of quality planting material of the biofuel feedstocks,
• Earning foreign currency through exports	• Awareness creation on the importance of biofuels, Increasing country's energy secutiy

(Source: Authors)

Figure 5: Oil processing factory (left), jatropha seeds damped (middle and right) in Bati, Amhara region of Ethiopia
(Source: Authors)

Burning sugarcane leaves and tops emits smoke that adversely affects people. In green sugarcane harvesting, sugarcane is harvested without burning, and a thick leafy residue (commonly called "trash blanket" or trash) remains on the soil surface. Sugarcane trash blanket has both negative and positive effects on the emergence and growth of the next sugarcane crop.

The sugar factories were using wastes of sugarcane crushing for soil amelioration, which naturally have high rate of decomposition that releases methane. It could be advisable to construct biogas technologies to get clean energy and bio-slurry as organic fertiliser. Moreover, the use of wastes in ethanol production can serve as a site for microalgae and biodiesel production. Integrating the biological and thermochemical activities in the forest can produce biodiesel, ethanol, biogas and bio-oil as alternative energy sources in addition to soil amelioration from biochar, all contributing to reducing GHGs emissions and creating good conditions for developing or enhancing a circular green economy (Figure 6).

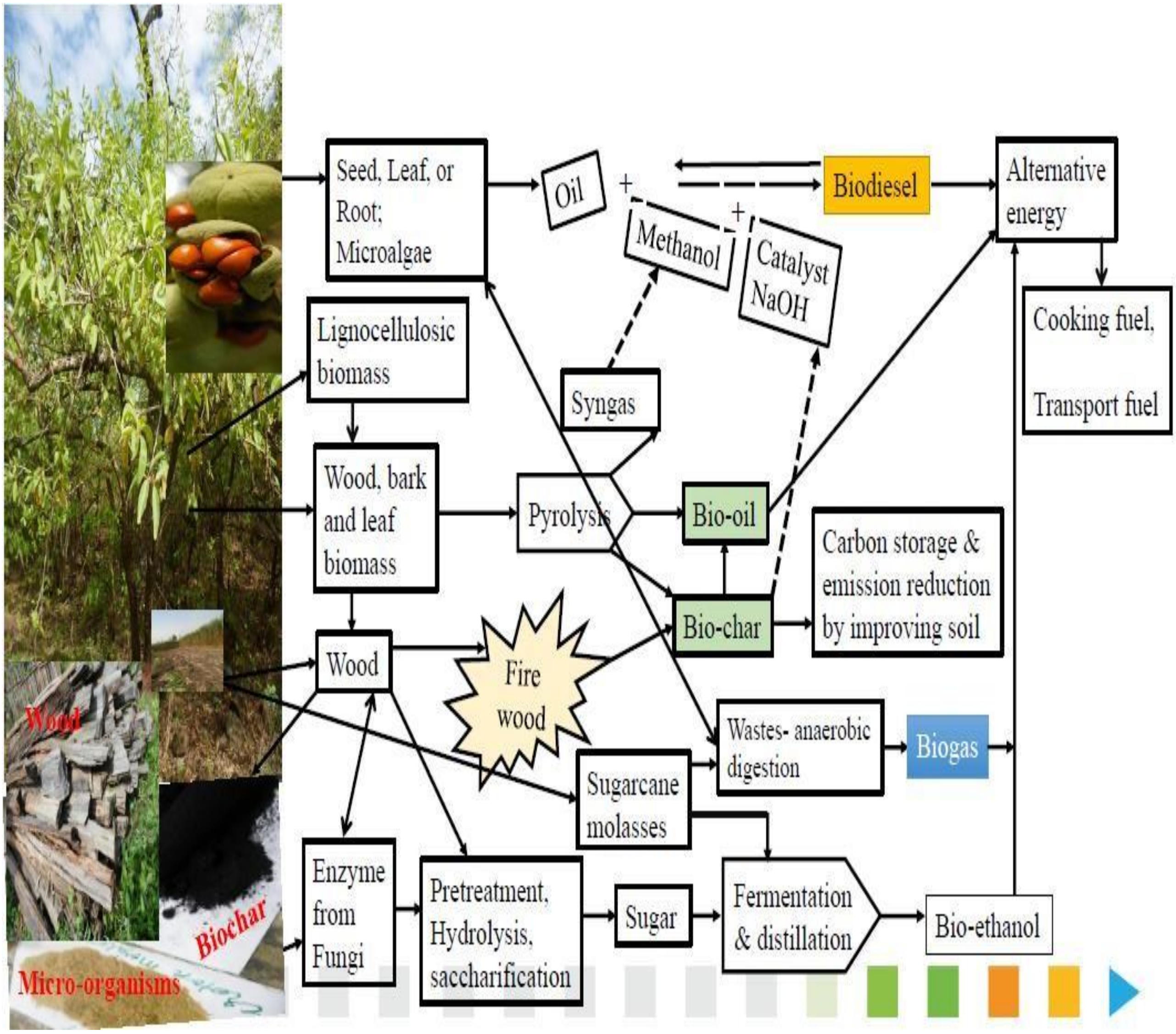

Figure 6: Integration of biofuel alternative energy sources and GHG emission reduction (Source: Authors)

Table 9. Major challenges in liquid biofuel production in Ethiopia, Kenya, and Tanzania

Major challenges	Ethiopia	Kenya	Tanzania
Institutional challenges	• Weak coordination among different agencies involved in biofuel development. • Frequent structural changes in relevant administrative structures, • Lack of clarity on responsibilities at Federal and Regional levels.	• Inadequate policy and regulatory support as well as weak institutional arrangements.	• Absence of proper policy guidance • Absence of institutional memory on biofuel activities
Market challenges	• Buyers cannot get sufficient amount of biofuel feedstocks for liquid biofuel production. • In some cases, sellers had no market for the small biofuel feedstocks because of absence of local processing facilities.	• Inadequate market development and investments in first generation biofuels made biofuel production unattractive.	• Sales of biofuels in existing gas stations constrained due to lack of blending ratios.
Economic challenges	• High initial investment costs made worse in marginal areas and due to unfavourable global financial situation. • At the market level, the petroleum price was by far lower than liquid biofuel price in 2021	• Limited sources of investment capital	• Lack of initial price guarantee for biofuels which require fixed prices by the central government) to facilitate entry into markets
Social	• Lack of local community support in potential feedstock production areas • Lack of feasibility study to guide investments • Land use conflicts in potential feedstock production areas	• Biodiversity loss and conflict with local people in potential feedstock production areas	• Competition with other land uses and irrigation water sources as well as possibilities of precipitating food insecurity
Technical challenges	• Lack of technical capacity and skills in the industry, • Lack of silvicultural/ agronomic techniques for crops, • Infestation by pest and disease on biofuel feedstocks, • Absence of quality standards for products, • Lack of clear definition of "marginal land" that was felt suitable for biofuel production, • Old ethanol producing factories characterized with poor maintenance and lack of spare parts	• Lack of quality planting material • Feedstocks attacked by pests and diseases, • Lack of enough trained people, • Non-mechanized system for feedstock production	• Expensive liquid biofuel production technologies.

Major challenges	Ethiopia	Kenya	Tanzania
Legal challenges and incentives	• There was limited incentive in biofuel production and blending		• Lack of long term, stable and clear policies, regulations and incentives
Productivity	• Poor productivity of biofuel crops, • Low levels of ethanol production for fuel	• Low quality planting materials • Poor productivity of biofuel feedstocks	• Poor productivity of feedstocks in degraded and marginal lands
Experience in production, monitoring and evaluation	• Fresh graduates with limited administrative and technical experience managed biofuel projects • Lack of monitoring and evaluation of investments	• Weak follow up to sustain the liquid biofuel sector.	• Inadequate knowledge on land rights and biofuel production and related issues • No follow up to sustain the liquid biofuel sector.
Land tenure	• Land ownership remains with the state and there was fear of future tenure change.	• Unclear land tenure system	• Unclear land tenure system
Weak research and inadequate information	• Instability of research coordination among institutions responsible for bioenergy activities	• Poor research on breeding of quality planting material.	• Lack of research to guide matching areas with suitable and profitable feedstocks

(Source: Authors)

Table 10. Coping mechanisms for addressing the challenges in liquid biofuel production

Coping mechanisms for biofuel challenges	Ethiopia	Kenya	Tanzania
• Institutional reform	• Key government institutions responsible for biofuel development need to be strengthened at regional, zonal and district levels, • Policy reforms needed to cope up with the failure of biofuel investment.	• Formulation of regulatory support and well-structured institutional arrangements, and guaranteed markets.	• Formulation of framework to support biofuel development at relevant ministry or department level
• Market access	• Creating local markets facilitated by the government like was done for sugar factories and establishment of a biogas agency for the country, • Facilitate linking farm producers with small and medium enterprises.	• Governments to facilitate development of local of markets	• Institute liquid biofuel blending ratios and facilitate creation of relevant local enterprises.
• Access to credit and grants	• Provision of credit to the biofuel producers' associations at low interest rates and with a grant of interest free period • Soliciting for innovative financial mechanisms	• Provision of credit to the biofuel producers at low interest rates and with a grant of interest free period	• Provision of initial good price guarantee for biofuels products (e.g., through fixed prices by the Government)
• Awareness creation	• Creating awareness of potential for biofuels production and use and their benefits at the local community level, • Determination and demarcation of land and plant species for biofuel feedstock production guided and done at local community level, • Conducting feasibility study and environmental impact assessment on the profitability of biofuel production and utilization • Promoting smallholders and out growers' participation	• Local determination and demarcation of land and plant species for biofuel feedstock production • Biodiversity hotspots protected from biofuel crop production • Feasibility study and environmental impact assessment of liquid biofuel	• Determining land, plant species and irrigation water sources for surrounding farmers and for biofuel production, • Creating awareness of potential for biofuels production and use and their benefits at the local community level, • Feasibility study and environmental impact assessment
• Capacity building	• Building capacity of staff and laboratories, • Training in growing and management of biofuel crop production,	• Training sufficient number of technical people,	• Training people to modify relevant motor engines to use liquid biofuels

Coping mechanisms for biofuel challenges	Ethiopia	Kenya	Tanzania
	• Government support to contain power shortages, tool and equipment maintenance in sugar factories.	• Creating mechanized system	
• Introducing stepwise blending levels	• Fixing the blend ratios of biodiesel and bioethanol depending on the availability of feedstock in the country,	• The same as in Ethiopia	• The same as in Ethiopia
• Provision of tax waivers, subsidies and other incentives	• Tax waivers introduced on importing fuels, tools and equipment required for liquid biofuel production and blending, • Financial incentives introduced to attract the private sector in oil distributing companies and for blending,	• Addressed transport tariffs on imported fossil fuel so as to increase the demand for locally produced biofuels.	• Establishment of long term, stable and clear policies, regulations and incentives.
• Productivity improvement	• Improving productivity of biofuel plant species by selecting, diversifying breeding, and also through enhancing soil fertility,	• The same as in Ethiopia	• The same as in Ethiopia
• Sustainable management	• Development of monitoring and evaluation strategies for liquid biofuel, • Establishment of institutional clear mandates in liquid biofuel sector. • Promotion of local technologies to supply spare parts,	• The same as in Ethiopia	• The same as in Ethiopia
• Policy on land tenure	• Establishing clear land tenure system and secure land ownership	• Establishing clear land tenure system	
• Disseminate research information	• Researching on highly productive and profitable biofuel crops; including research on breeding of quality planting material, with high yield, and water use efficiency, for liquid biofuel production.	• The same as in Ethiopia	• The same as in Ethiopia

(Source: Authors)

The sustainability of bioethanol production was generally fluctuating because of biomass supply and company level technical issues. In the case of biomass feedstock supply, interviewed bioethanol and biodiesel producing factories and key informants provided different responses. The responses were on feedstock, on cost of technology and financing, markets through mandates and targets, consumer demand, and environmental and social issues. Accordingly, the responses were categorized on levels of agreement as strongly agree; agree; neither agree nor disagree; disagree; and strongly disagree as shown in Table 11. Most of the responses were agreeing on the issues, risks and barriers. For example, about the presence of enough incentives to companies to grow feedstock for biofuel plant, 63.6% agree that there is lack of incentives, 9.1% of the respondents strongly agree and the same per cent strongly disagree. With regard to marketing, the policies affecting the business were reported as not being stable and clear, with 36.4% strongly of this view, 45.5% moderately of this view and 18.2% undecided (Table 11).

Table 11. Perception of different stakeholders on liquid biofuel production in three countries

Issues, Risks and Barriers	Percentage of respondents				
Feedstock:	SD (1)	D (2)	NAD (3)	A (4)	SA ((5)
Companies do not get enough incentives to grow feedstock for biofuel plants.	9.1	0.0	18.2	63.6	9.1
There is not enough feedstock for advanced biofuels business expansion.	0.0	9.1	36.4	54.5	0.0
Smallholder farmers are willing to sacrifice land for biofuel feedstock production	0.0	18.2	9.1	63.6	9.1
There is inadequate regulation for biomass feedstock quality in the country/region	0.0	9.1	9.1	63.6	18.2
Competing uses for biomass feedstock (such as heat, power and bioproducts) pose a major risk for our biofuel business.	0.0	18.2	18.2	54.5	9.1
Biofuel feedstock can outcompete food production and water	0.0	9.1	9.1	63.6	18.2
Biofuel feedstock caused deforestation and reduced stream water levels	0.00	7	11.2	18.2	63.6
Better mechanisms are needed to monitor biofuel feedstock prices	0.0	9.1	18.2	63.6	9.1
Biomass transport and storage logistics are not available at volumes required by full-sized biorefineries.	0.0	0.0	0.0	100.0	0.0
Feedstock price uncertainty hampers our business.	0.0	0.0	18.2	63.6	18.2
Feedstock quality variations disrupt our production.	18.2	63.6	18.2	0.0	0.0
Cost of technology and financing:					
The eastern Africa region is not ready for second level generation biofuel due to technology constraints	0.0	9.1	9.1	63.6	18.2
Eastern Africa countries can afford the technology that goes with large scale advanced biofuels deployment	0.0	9.1	18.2	54.5	18.2

Issues, Risks and Barriers	Percentage of respondents				
Inadequate transport infrastructure will constrain the marketing of advanced biofuel products.	18.2	36.4	18.2	27.3	0.0
Eastern Africa countries will be producing second generation biofuels at significant levels in the 2040.	0.0	0.0	36.4	63.6	0.0
Lack of funding /financing is a major barrier to investment in advanced biofuels.	0.0	0.0	9.1	9.1	81.8
Markets through mandates and targets:					
Policies affecting our business are stable and clear	36.4	45.5	18.2	0.0	0.0
Mandates and blending obligations for advanced biofuels should be strengthened by price mechanisms like rebates, tax credits, reduced tax rates, and a market value for carbon.	0.0	0.0	18.2	18.2	63.6
Eastern Africa renewable fuel targets are insufficient to encourage investments in advanced biofuel production	0.0	0.0	36.4	36.4	27.3
Eastern Africa biofuel markets are too fragmented, more coherent central regulation is needed.	0.0	0.0	45.5	54.5	0.0
Targets for expansion of advanced biofuels production are not sufficiently ambitious.	0.0	0.0	0.0	81.8	18.2
Regulatory uncertainty impedes investments in advanced biofuel production.	0.0	0.0	0.0	81.8	18.2
Blending limits discourage investment in advanced biofuel production.	0.0	0.0	0.0	81.8	18.2
Eastern Africa governments should increase blending ratios and introduce flexi-fuel vehicles even if it's at a small scale to create local market for biofuels.	0.0	0.0	54.5	27.3	18.2
Import tariffs are needed to protect domestic investments in advanced biofuels.	0.0	0.0	0.0	100.0	0.0
Import tariffs have a negative impact on eastern Africa biofuel operations.	36.4	36.4	27.3	0.0	0.0
Consumer demand:					
Introduction of Flex-Fuel Vehicles (FFVs) in East Africa could inspire biofuel production in the region	0.0	0.0	0.0	54.5	45.5
The future of eastern Africa biofuels is dependent on the customer.	0.0	0.0	36.4	36.4	27.3
Introduction of electric vehicles (EVs) in the developed world pose a serious threat for biofuels business even in eastern Africa	0.0	0.0	54.5	45.5	0.0
International agreements will eventually limit greenhouse gas emissions in transport by forcing them to use biofuels.	0.0	0.0	0.0	81.8	18.2

Issues, Risks and Barriers	Percentage of respondents				
Sales of biofuel by-products and co-products is a necessary part of business to increase profits and encourage more companies to invest	0.0	0.0	0.0	81.8	18.2
Environment and social	0.0	0.0	0.0	0.0	0.0
Biofuel production will not increase GHG emissions, land use change and indirect land use change	18.2	27.3	54.5	0.0	0.0
Conflicts over land could be more prominent due to expansion of biofuel feedstock	18.2	27.3	54.5	0.0	0.0
Smallholder farmers will not benefit from biofuel expansion due to small land holdings	27.3	72.7	0.0	0.0	0.0
Food-vs-Fuel debate continues to push advanced biofuels business forward.	0.0	0.0	0.0	54.5	45.5
Environmental advocacy groups have not helped advance the production of biofuel generation biofuels.	0.0	0.0	27.3	27.3	45.5
Biofuel's production will result in increased poverty and food insecurity	45.5	27.3	27.3	0.0	0.0

Note: Feedstocks issues: Key: SD = Strongly Disagree; D = Disagree; NAD = Neither Agree nor Disagree: A = Agree; SA = Strongly Agree
(Source: Authors field survey summarized from Ethiopia, Kenya and Tanzania)

The use of first-generation crops such as jatropha, croton, sugarcane and sweet sorghum could compete with food crop land making second generation lignocellulosic biomass sources better alternatives. From Table 11 about 64% of the respondents informed that "biofuel feedstock can outcompete food production and water" while 73% of the respondents do not see this as a potentially serious threat since they contended that biofuels production will not result in increased poverty and food insecurity. In fact, about 64% report that smallholder farmers are willing to sacrifice land for biofuel feedstock production because many respondents (55%) already see that there is not enough feedstock for advanced biofuels business expansion (Table 11). However, globally, the conventional feedstocks such as corn and sugarcane are not in sufficient quantities to also cater for global bioethanol production because they are also needed for human food and animal feed.

3.4 Effect of liquid biofuel production on cropland, forest margins, and food security

3.4.1The effect of liquid biofuel production on cropland

Growing biofuel feedstocks in agricultural, grazing and forest land was observed to have different effects. The biofuel investments affected crop land in different ways in all areas visited. It was further observed that these investments were largely not based on pre-assessment of land-use plans.

From Table 11 about 64% of the respondents informed that biofuel feedstock could out compete food production and water; stressing that water levels in streams were reduced after forest clearance for biofuel crop production. However, biofuel crop planting activity in degraded land improved the water resources because those biofuel feedstock crops protected the soil and conserved water. For example, jatropha plantation in Bati woreda in northern Ethiopia served as gully rehabilitation and reduced the water erosion.

Implications on food security

In eastern Africa countries the biofuel investments were of project nature, with occasional project funds that supported farmers for the biofuel feedstock. During the project the local people shifted to paid jobs as their means of income source when they gave up their land (through project support). However, this support was later stopped when the projects terminated. When the local people got the land back in short period of time they could resume the agricultural practice, and therefore, it cannot be claimed that in such situation's food security was impaired. Many of biofuel production initiatives were collapsed, and with biofuel crop planting having no long-term food security effect. In fact, from Table 11, over 70% of the respondents were of the view that biofuels production will not result in increased poverty and food insecurity. Also, about 64% reported that smallholder farmer was willing to sacrifice land for biofuel feedstock production; implying that they did not see an immediate threat to food security arising from growing biofuel feedstocks.

In Kenya, the productivity of biofuel feedstocks or food crops per unit area was below the expected maximum due to low quality planting materials, and poor management. The biofuel investments in most cases were abandoned and the land areas replaced by bushes, shrubs or converted to agricultural land. In Tanzania, farmers, environmentalist, and NGOs prompted the Tanzanian government to suspend the allocation of arable land, processing any new applications for biofuel projects and eviction of farmers over biofuel projects, pending ratification of a law and establishment of a regulatory mechanism to govern the sector and monitor the biofuel industry. In Tanzania, initially farmers faced a trade-off between selling their food to the biofuel producing companies or retaining it as food. This happens when the price of the food crops is higher in biofuel producing area than selling or retaining it as food. This could lead to localised shortage of food to the community. Experience from Action Aid (2010) reported the vulnerability of rising in food prices in rural households as the results food shortages linked to over selling.

Effect on forest covers due to deforestation and forest degradation

The effect of biofuel production on crop and forest land was associated with displacement of land. In all parts of the study areas in eastern Africa farmers complain about the land taken for jatropha and castor bean production. From Table 11, about 64% of the respondents reported that biofuel feedstock caused deforestation and reduced stream water levels.

For example, the forests in western Ethiopia, Gambella and Benshangul Gumz, were cleared for oil palm and jatropha cultivation. In eastern Ethiopia, in Babile elephant sanctuary and surrounding districts, about 10,000 ha of primary forest land was cleared for castor biofuel crop production. The forest was meant for unique elephant population that exists only in east Africa (BirdLife Africa Partnership, 2012), thus disrupted migration routes. The allocation of forest and agricultural land for liquid biofuel crop production caused conflict with local people. The investment also destructed wildlife habitat (Gebreegziabher *et al*., 2014). In Ethiopia, over 80% of biofuel developments were done in arable lands, forest lands and woodlands (MELCA Mahiber, 2008). A land use land cover change in one of the sugar factories of Ethiopia, called Fincha, which made expansion to produce additional liquid biofuel showed that cultivated land, settlement, and sugarcane plantation increased at a rate of 579.8 ha/yr., 141.2 ha/yr. and 137.1 ha/yr., respectively, whereas wetland, forest land and bare land reduced by 600 ha/y, 328.7 ha/yr. and 60.3 ha/yr., respectively, in 1987–2019 (Tolessa et al.,

2021). The wet land and forest lands were the main victims of many of the biofuel investment in Ethiopia.
In Kenya, the investment in biofuel production was said to be neither in forest land nor in settlement areas which could cause deforestation and displacement of people. Biofuel investment was mainly on grazing land, degraded land and other suitable marginal land. BirdLife Africa Partnership (2012) stated that in Kenya, over 20,000 ha of forests were deforested in Tana River Delta and Dakatcha woodlands for sugarcane plantation; these are areas that are important bird habitats, seasonal grazing lands, and regulators of the flow of River Tana. Clearance of mountains for biofuel production raised complains and conflict with environmentalists. In Kenya, land cover change transitions between 1988 and 2017 as a proportion of land area was 0.86% ±0.47 mainly because of deforestation of dense forest (Bullock et al., 2021).

In Tanzania, clearing of natural vegetation such as Miombo woodland and the montane forests resulted in loss of watersheds which provide important source of rivers. The consequences of clearing of large areas of natural forest habitats to give way to biofuel mono crops farming resulted in loss of biodiversity and a possible cause to create a “carbon debt” by releasing significant greenhouse gas (GHG) emissions (Markensten and Mouk, 2012) and blocked the route followed by wild animals. Biofuel development created biodiversity loss, land conflict, labor issues, and indigenous right issues (Hance, 2015). In Kisarawe District Coastal Forests which are important habitat for endemic and endangered bird species, endangered primate, and transit route for elephants and buffaloes, sources of edible wild plants, pottery soils and water were partly deforested for jatropha plantation (BirdLife Africa Partnership, 2012). A land use land cover change (LULCC) study conducted in Tanzania revealed a significant increase in cultivated land, a decrease in forested land and encroachment into forest reserve from 1985 to 2011. The conversion of land used for crop production into jatropha farming caused direct and indirect land use changes in the area. In Kisarawe district, bare land area was converted to 8,613ha agricultural land because of the introduction of jatropha farming (Mwakapuja et al., 2017).

Eastern Africa countries have undergone extensive environmental change in the past three decades, largely driven by the expansion of cropland and the conversion of naturally vegetated land covers by factors like biofuel crops. From 1988 to 2017, the area of cropland and settlements increased and largely reduced in woody vegetation (Bullock et al., 2021). Open forest (natural and planted forests tree-covered areas with 15–40% canopy cover) is commonly observed in eastern Africa countries when compared to dense forest (natural and planted forests tree-covered areas with over 40% canopy cover) (Olson et al., 2001). Deforestation of open forest occurred most frequently in Tanzania. However, the exact effect of biofuel development on deforestation and land use land cover change was not determined because the areas of biofuel investment in most cases was abandoned and the land areas was replaced by bushes, shrubs or reverted to agricultural land.

3.5 Trade and competitiveness of eastern Africa biofuels in the international markets

Increasing the growth of domestic and international biofuel markets depends on increasing availability of feedstocks because a major constraint to the growth of biofuel markets is development of biofuels feedstocks. In fact, from Table 11, about 55% of the respondents already see that there is not enough feedstock for advanced biofuels business expansion in the eastern Africa region. For example, in Ethiopia, ethanol demand has been growing to substitute for transport gasoline and household kerosene, as well as because of demands in pharmaceutical and alcohol beverage industries.

In all countries surveyed, there was a noted considerable potential domestic and foreign market for liquid biofuel because of large population size and external cooperation. Ethiopia, Kenya and Tanzania are members of the Common Market for Eastern and Southern Africa (COMESA), embracing 20 countries with a population of about 380 million, and have market access at preferential tariffs. Eastern Africa countries also have potential accesses to the Middle East, European, and USA markets.

The internal markets can play great role in the production of liquid biofuel by fueling demand. For example, in Ethiopia the blending for the transport sector from 2009 to 2015 was about 48,028.6 kiloliters of ethanol that saved of the country US$39.6 million from importing fossil fuels. The highest earning was in 2011/12 at about US$9.23 million USD; however, after 2015 the blending was interrupted by the insufficient production of ethanol in the sugar factories (Figure 7).

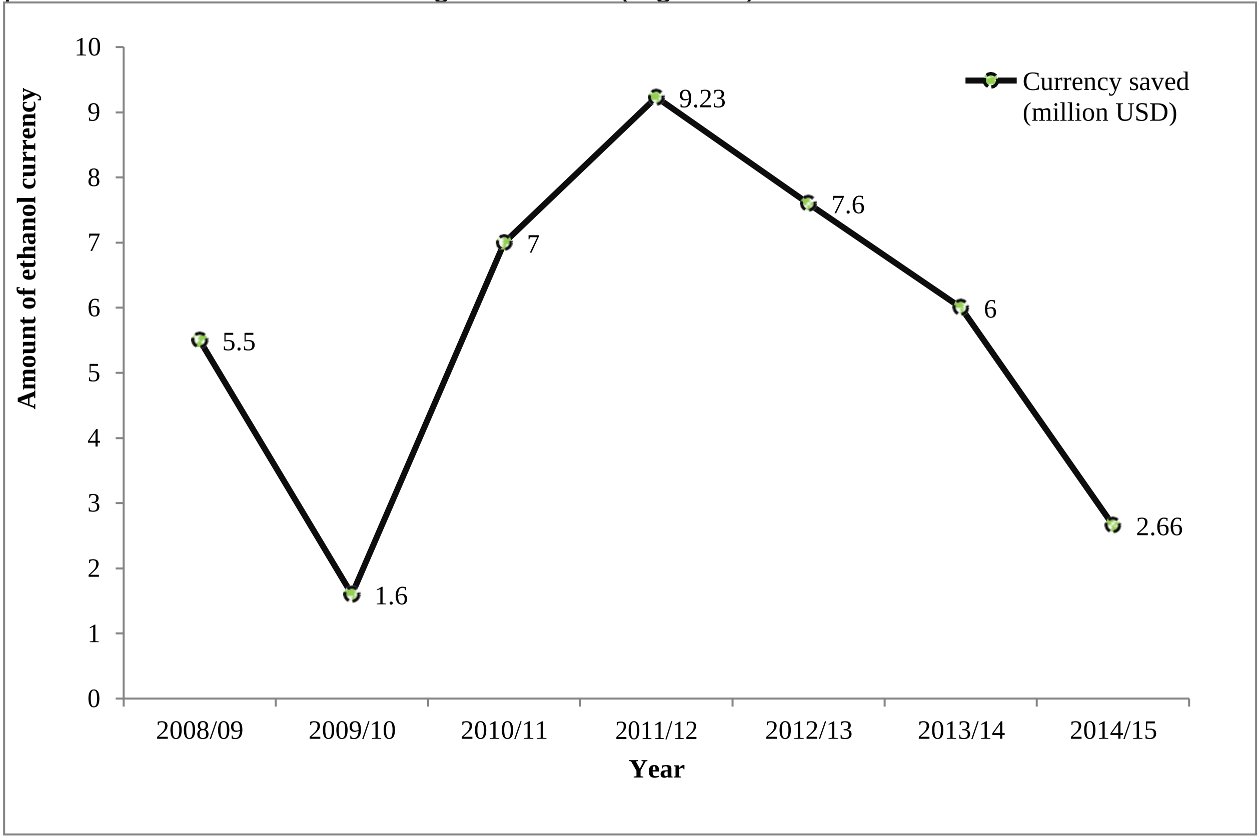

Figure **7**: Ethanol blending saved USD currency from 2009 to 2015
(Source: Authors analysis of review data)

During the initial stage of the COVID 19 pandemic March 2020 to February 2021 the demand for ethanol increased. However, the increase in excise tax on ethanol during this period reduced its demand from local sources, making the country to import ethanol from India free of tax by private companies that produce sanitizers; effectively making the price of imported ethanol lower than the one produced within Ethiopia.

Ethiopia introduced a mandatory blending requirement of E5 in 2010, increasing it to E10 in March 2011. Between 2008 and 2012 around 32.8 million litres of fuel ethanol were produced, saving around US$25 million by blending anhydrous bioethanol with gasoline. The use of full capacity of sugar factories to produce ethanol could enable Ethiopia to compete in the international markets, given that the country has in the past successfully exported these products to Sweden and Italy.

In Kenya, bioethanol production emerged at the end of 2011 through the preferential trade terms on sugar that were agreed with other producers within COMESA. Kenya had been using imported ethanol as cooking fuel for low-income urban dwellers. The cost of bioethanol is inflated by a 25% import tariff and a 16% value added tax (VAT). If the Government of Kenya made bioethanol zero-rated for VAT and eliminated tariffs, it could displace charcoal and kerosene (Dalberg, 2018). The import could be from the neighbouring countries like Ethiopia. In Kenya, biofuel investment is socially acceptable because of job creation, reduction in unemployment, income increment, increasing energy supply and reducing soil erosion.

In Tanzania, transport sector is primarily road-based, and its demand for fuel is growing rapidly. Biofuels offer significant potential to contribute to Tanzania’s energy mix, especially in the transport sector. In 2007 *Jatropha curcas* was identified as one of the most exciting potential energy crops in Tanzania; however, this potential has not been realized. Tanzania had four main sugar mills in 2011, all of which had plans for investment and expansion. However, priority was given to sugar production (the country was a net importer) and better efficiency by clustering smallholder farms to improve agricultural practices and logistics management.

In eastern Africa, although investments in biofuels are currently not profitable, the market is projected to grow nationally and internationally with projected economic development and increased environmental awareness. The eastern Africa countries should promote research that will increase the understanding of the best ways of producing different feedstocks as well as to increase their productivity, among other things; given that liquid biofuel is relatively new in the countries, and that most relevant issues around biofuel are unknown. Also, most of the major problems that can arise with biofuel and other large-scale agricultural investments are associated with land rights, and this is an area where that requires better understanding to forestall conflicts.

3.5.1 The quantity and type of eastern Africa biofuels in the international markets

The eastern Africa countries had bioethanol production and E5 to E10 blending programs in early 1980s in Kenya and in 2009 in Ethiopia, located in their capital cities. The reduction in capacities of sugar factories and the low attention given to ethanol fuel production (because of drop in global fossil oil prices, and an increase in the price of beverage ethanol for alcoholic consumption), the ethanol had been sold to beverage factories within and outside these countries. Kenya was selling beverage ethanol to Uganda and Democratic Republic of Congo in the late 1980s. After 2007, blending ratios were planned to be issued by the energy regulator in Kenya, from time to time; however, according to the ministry responsible for energy new blending ratios were not issued; they were being revised at the time of collecting data for this study. In Ethiopia, blending of ethanol with gasoline commenced in 1979 with the cooperation of Ministry of Industry and UN-Industrial Development Organization (UNIDO) following a feasibility study conducted by the State Alcohol Monopoly of Finland Ltd. Then a French expatriate undertook a feasibility study of the production of yeast and bioethanol from molasses (Sugar Corporation, 2013). One of the sugar factories called Fincha sugar factory was producing 6 million liters anhydrous ethanol annually since 2005 because of contract agreement entered with an Italian company, and with an ex-factory price of US$0.202 per litre, until when the government banned its export and to use it for local gasoline blending (Tekle, 2008).

In Kenya, there has been import of ethanol from USA and other countries; however, there was no information on the export of ethanol from the country. In Tanzania, there was no record of exporting ethanol; the country mostly depends on imports.

3.5.2 The quality and type of eastern Africa biofuels in the international markets

Quality test of bioethanol was done by simple thermometer and alcohols meter. The quality of bioethanol was determined based on ISO certificate. The alcohol level of bioethanol for transport fuel was ⩾99.9% (0.1% water) depending on ISO standards. The fuel stations and companies provide feedback on the quality of bioethanol. ISO bioethanol production procedure has been employed stepwise. In Ethiopia, the government has been monitoring oil distributing companies with regard to safety measures and operations that secure the quality of the blended gasoline. However, there was no practical quality control mechanism for the final blended gasoline at fuel stations, resulting into absence of quality standards, because the fuel stations are operating in the already installed infrastructure for distributing pure gasoline. To overcome this, the existing gasoline distribution infrastructure has to be modified. In Kenya, Kenya Bureau of Standards (KEBS) was supposed to ensure quality of biofuels and setting of blending standards, but these were not available when this study was undertaken. In Tanzania, due to lack of regulatory framework for quality standards, there was no quality control.

Liquid biofuels are not sufficiently available in the local market. This study noted, therefore, that eastern Africa biofuels cannot compete in international markets.

From Table 11, most of the respondents emphasized the following with respect to improving the biofuel industry and, by extension, making it competitive at all levels:

- Policies affecting the biofuel business should be clear and stable,
- Mandates and blending obligations for advanced biofuels should be strengthened by, for example, favourable price mechanisms like tax rebates, tax credits, reduced tax rates, and a good market value for carbon,
- Eastern Africa renewable fuel targets are not sufficiently ambitious to encourage substantial investments in advanced biofuel production,
- Eastern Africa biofuel markets are small and very fragmented; more coherent favourable central government policies and regulations could promote their growth, size, and efficient in operations,
- Environmental advocacy groups have not helped advance the production of biofuels,
- Introduction of Flex-Fuel Vehicles (FFVs) in East Africa could inspire biofuel production in the region,
- Eastern Africa countries can afford the technology that goes with large scale advanced biofuels deployment,

- Biomass transport and storage logistics are small and cannot support biofuel quantities produced by full-sized biorefineries,

3.6 Policy and institutional frameworks for sustainable biofuel production in eastern Africa

In eastern Africa, some regulations in biofuel investment forbid clearance of forest lands for biofuel production, giving preference to promoting feedstock production on degraded land that does not compete with food production (Table 12). The focus of biofuel development is linked to rural renewable energy development and climate change adaptation and mitigation.

While there are policies and regulatory frameworks in all the countries, how they feature in the biofuel production value chain matters a lot. As can be discerned from Table 12, the eastern Africa countries are at various levels in terms of policies and regulations to support sustainable production, transportation and consumption of liquid biofuels. Many institutions along the value chain appear to lack or have weak policies and regulations that facilitate, for example, access to land for substantial investments in feedstock production (unclear land tenure arrangements), insufficient scientific information to guide choices on suitable biofuel crops, unclear institutional mandates on biofuel production and blending, insufficient guidance on transportation, storage and consumption of liquid biofuels. In fact, from Table 11, the respondents informed that regulatory uncertainties impede investments in advanced biofuel production and blending limits discourage investment in advanced biofuel production. Further, they informed that biomass transport and storage logistics are not available at volumes required by full-sized biorefineries.

The above notwithstanding, in Ethiopia the liquid biofuel activities are guided by the country biofuel strategy of 2007, and biomass strategy of 2013. In Kenya, the policies in liquid biofuel include *National Biofuels Policy (2010)*, the *Strategy for Developing the Biodiesel Industry (2008-2012) and Biomass Strategy 2013*. Table 12 highlights what is in these policies and strategies and their strengths and weaknesses, while Table 13 presents some of the institutions charged with implementing these policies and enforcing the regulations.

3.6.1 Problems and deficits in the biofuel strategy and related policies

The policies earlier to these ones specific to biofuel production had the biofuel sector in the overall energy policies of the countries, making earlier efforts on biofuel production to fail or weaken because government support shifted to priority energy sources like hydro power in Ethiopia and Tanzania, and to geothermal energy in Kenya (GTZ, 2007). This led to massive failures in the initial efforts to embark on serious commercial biofuel production since 2007. Such investments were abandoned in the countries without further generation of income from biofuel crops on local community lands taken up for these investments. For example, in Ethiopia the land taken from local communities created conflicts between local development professionals and the farmers. The farmers lost trust on the local development agents and professionals because the promised income from the widely planted jatropha (in more than 48 districts) and other biofuel crops was not realized. Similarly, large areas of jatropha, castor and croton planted in Kenya and Tanzania were abandoned. Tables 12 and Table 13 highlights many reasons for failure of such investments, including the following:

- Lack of sustainability focus and standards on producing processing and consuming liquid biofuels. As a newly emerging sector, biofuel development must have standards that also provide clarity and accountability among actors engaged across the value chain. There are no standards for biofuel development operators and professionals working in the field. In the absence of clear standards and guiding principles it would be difficult to achieve the set objectives and gains expected in national biofuel policies and strategies.
- Lack of consensus on definition of marginal land that was earmarked for planting biofuel crops.
- Lack of clear mandate of the different ministries engaged, and regional offices to enforce regulations, such as land allocation, feedstock type selection, licensing and promoting investments, and standardization practices (Table 12).
- Lack of appropriate technologies in the different steps of liquid biofuel production and processing. Small-scale biofuels production for local consumption could add to efforts to modernize rural areas. However, this requires additional local efforts to develop technologies to realise this.
- While Ethiopia and Tanzania employed the concept of "one-stop-shop" for investments that also include those for biofuel development, this was not accompanied with provision of private sector incentives to invest on biofuels. This partly made the few local and international private sector investors in biofuel development to abandon the sector. Incentives are necessary tools to encourage entrepreneurs to invest in biofuel production (Table 13).

Table 12. The strengths and weaknesses of policies in development of liquid biofuel in Ethiopia, Kenya, and Tanzania

Country	Objective/What exists	Strengths	Weaknesses
Ethiopia	• Produce adequate biofuel energy from domestic resources for substituting imported petroleum products and to export excess products, • Promote investment in forestry • Ensure social and environmental sustainability of biofuel. • Expand ethanol production by investing in more sugar estates with ethanol mills produce million liters of biodiesel.	• Plan to reduce deforestation through replacing firewood by liquid biofuel, • Existence of an ethanol blending policy, E5 in 2009, E10 in early 2011; and amendments to agricultural development and taxation policies made to attract large-scale investments in agriculture including biofuels, • Plans to substitute fossil fuels in the transport sector. • Promotion afforestation and developed renewable energies	• The institutions lack clear mandate on liquid biofuel sector. • Insufficient research information for biofuel policy to guide to growing bioenergy crops and to provide land for this. • The energy policy of 2012 does not explicitly mention development of biofuels. • Local people lack incentives to embark on this sector

Country	Objective/What exists	Strengths	Weaknesses
Kenya	• Prohibit clearance of forest lands for biofuel feedstocks cultivation • Promote feedstock production on degraded land that does not compete with food production. • Strategies for promotion of collaboration with development partners mandate the government to facilitate the production of biofuels and also direct KEBS to ensure quality of biofuels and set blending standards. • Available instruments and tools for assessing proposed development activities to ensure they are economically viable, socially acceptable, and environmentally sound.	• Policies that could lead to the establishment of research activities on liquid biofuels • Central government facilitates the production of biofuels. • Available strategies for preservation and conservation ecosystems. • Benefitted from Clean Development Mechanism (CDM) in the sugar industry using co-generation of electricity.	• All the institutions lack clear mandates. • Insufficient research information for biofuel policy to guide to growing bioenergy crops and to provide land for this.
Tanzania	• Formulate guidelines for investments in the biofuel sector. • Project Document on “Strengthening the policy, legal, regulatory and institutional framework for bioenergy development in Tanzania.	• Tanzania Investment Centre (TIC) was the one stop Centre for task force all biofuel investment in the country • Guidelines and sustainability criteria developed by Task force. • In the guidelines, “Liquid biofuels which include biodiesel and bioethanol can be blended with petroleum products at various ratios.	• Tanzania has no policies developed to aid sustainable production, transportation and consumption of liquid biofuels. • Both policies, legal and regulatory frameworks were in draft form. • TIC was weak on coordination efforts.

(Source: Authors)

Table 13. The strength and weakness of institutions for liquid biofuel industry in eastern Africa

Country	Institutions for biofuel development	Strength	Weakness
Ethiopia	• Ministry of Mines and Energy (Ministry of Mines, Petroleum and Natural Gases (MoMPNG), • Ministry of Water, Irrigation and Energy and Ministry of Agriculture, • Regional energy offices • Ethiopian Institute of Agricultural Research and Ethiopian Environments and Forest Research Institutes	• Established bioenergy directorate, • Introduction/promotion of renewable energy sources and technologies such as solar, biogas improved stoves and • Initiation/promotion of liquid biofuels such as bioethanol, biodiesel, and other renewable energy sources • Researching on forestry, firewood and agricultural energy crops	• Lack of/weak coordination, lack of follow up, lack of silvicultural and agronomic management, insufficient or lack of market identification for liquid biofuel feedstock production • Activities at federal, regional and investment offices were not clear and were sometimes overlapping for example in land allocation. • Frequent administrative structural changes, • Lack of budget to conduct research,
Kenya	• Ministry of Energy, Ministry of Environment & Forestry, • Ministry of Lands & Physical Planning, and Ministry of Agriculture	• MOE has coordinated the formulation and development of many relevant policy and regulatory frameworks on liquid biofuels production and processing, formulation of policies to produce biofuels in nonresidential and on degraded lands	• All of the institutions related to biofuel issues lack clear mandate and no follow up to sustain the liquid biofuel sector.
Tanzania	• Ministry of Energy (MoE) by then Ministry of Energy and Minerals (MEM)	• Tanzania Investment Centre is the one stop Centre for all biofuel investment in the country	• All of the institutions related to biofuel issues lack clear mandate and no follow up to sustain the liquid biofuel sector. • Lack of policies to guide biofuel production, use and coordination • Lack of blending ratios. • Lack of institutional memory and documentation on past events on biofuel.

3.6.2 Policy directions

Following the initial failures in starting viable large scale commercial production of biofuel in the eastern Africa countries it becomes necessary to develop new and/or updating existing the biofuel policies and strategies to cater for, among other things, the provision of incentives to investors; strengthening of relevant institutions; development of directives/guidelines and standards to guide biofuel development, monitoring, and follow up systems. The policies and strategies could be developed along two dimensions namely political and strategic pillars. The political pillar needs to address the institutional strength of the ministry on the authority, coordination, and promotion of biofuel production at different levels through political actions. The strategic pillar needs to deal with developing strategic actions in both supply and demand, in order to strengthen the biofuel market by regulating prices, promoting high yielding feedstock crop varieties, and developing land use planning protocols (Table 14).

Table 14. Political and strategic pillars of biofuel development sector in eastern Africa countries

Policy dimension	Ethiopia	Kenya	Tanzania
Political pillars	Strengthening the authoritative body		The same
	Strengthening institutional capacity	The same	The same
	Coordinating among ministries		The same
	Establishing national markets	The same	The same
	Assist small-scale producers and smallholder farmers		The same
	Intercropping feedstocks with food crops		The same
	Avoiding use of basic food crops in biofuel production		The same
	Biofuel production with biodiversity conservation		The same
	Research bio-fuel crop productivity		The same
	Promote public-private partnerships		The same
	Collaborate with international actors		The same
	Link biofuel with emission reduction funding		The same
	Promote local processing capacity by installing processing factories	The same	The same
Strategic pillars	Establishment of national markets in addition to international market	The same	The same
	Value chain analysis and GHG emission determination in the lifecycle of liquid biofuels production and utilization	The same	The same
	Regulate prices of feedstock, liquid biofuel and blended fuel.	The same	The same
	Manage environmental impacts		The same
	Carry out capacity building	The same	The same
	Develop land use plans		The same
	Explore interactions between biofuel crops and ecosystem dynamics	The same	The same
	Mainstream research findings in development of biofuel crops	The same	The same
	Promote high yielding varieties based on agro-ecological areas	The same	The same
	Carry out regional and international stakeholder analysis		The same
	Maintain favourable policies and regulations		The same

(Source: Authors)

4. CONSEQUENCES OF FAILURE ON BIOFUEL INVESTMENTS

There were different negative consequences on the failure of the investment on liquid biofuel production in eastern Africa.

The farmers involved were left unhappy about the investment and with no trust on biofuel development agents. This is also confirmed by local biofuel developers' associations in Ethiopia.

The local people interviewed stated that the failure of biofuel production investments resulted in idle land earmarked for feedstock production, and loss of labour. The grazing and agricultural lands set aside for biofuel crop production and related investments were left idle and infested with weeds. The deforested areas for biofuel production lost their vegetation cover. The loss of woody vegetation was a potential cause of GHG emissions. Further, the land taken out of the usual farming activity was a cause of localised food insecurity as stated by all the interviewed stakeholders.

5.CONCLUSION

C1. The eastern Africa countries have large areas of land to produce biodiesel and bioethanol. The most common and potential feedstocks for liquid biofuel production in the region are jatropha (*Jatropha curcas*), Croton (*Croton megalocarpus*), Sweet sorghum (*Sorghum bicolour*), sugarcane (*Saccharum officinarum*), oil palm (*Elaeis guineensis*) and solid biomasses from forestry and agricultural residues. Biofuel crops such as switch grass, sweet sorghum and croton that can be grown widely by smallholder farmers in eastern Africa have not been introduced at the desirable commercial scale.

C2. The eastern Africa biofuel sector is guided by specific country-led programs that are in line with key political strategies, including those related to circular green economy; and involves public and private sector partnerships. While biofuel has a significant potential to play roles in enhancing socio-economic development and poverty reduction, at present, it represents insignificant energy source and its development specifically the biodiesel remains small and slow.

C3. The production of liquid biofuel investment ceased Ethiopia and Kenya in 2016 and in Tanzania in 2015. The initial implementation of biofuel production was mainly done by external support of few NGOs and donors. When external support was waned the biodiesel production stalled. These countries have sugarcane factories producing ethanol from molasses intermittently, and in insufficient quantities to support blending with fossil fuels to supply to the transport sector.

C4. In the period 2017-2021, the production of ethanol in the eastern Africa countries studied were from one or two sugar factories. The absence of the ethanol distillers, lack of sufficient spare parts to maintain old ethanol factories, and the lack of sufficient power reduced the potential production of ethanol. In addition, the molasses produced were partly wasted, used as cattle feed, and/ or sold to local beverage fermenters. However, if the countries possess the required ethanol distillers necessary to handle the ethanol production, the sugar factories could produce sufficient amounts to supply fuel that could substitute very significant quantities of imported gasoline. Given improvements of the existing technological conditions, the Ethiopian sugarcane factories can produce 432.41 million litres/year of ethanol, the Kenyan 289.28 million litres/year, and the Tanzanian 81.64 million litres/year. However, the factories were not producing bioethanol based on the full capacity of molasses because of old condition of the distillers, damaged boilers and interrupted power supply. The current annual production of ethanol is estimated at 24.25 million litres in Ethiopia, 8.25 million in Kenya and 1.4 million in Tanzania. On the other hand, if there is technological improvement to produce ethanol from lignocellulosic biomass and sugarcane bagasse processing, the total bioethanol production can be raised to 8.2 billion litres/year in Kenya, 10.8 billion litres/year in Tanzania, and to 35.7 billion litres/year in Ethiopia, quantities that are much higher than the imports of petroleum in these countries. The potential production of ethanol from lignocellulosic biomass is based on the existence of large quantities of this feedstock for the production of ethanol in eastern Africa countries. However, the technologies available to convert solid biomass to liquid biofuel are not widely available, and also require human and laboratories capacity development.

C5. Challenges in liquid biofuels production and utilisation include lack of enough trained people, non-mechanized system for feedstock production, lack of investment capital, lack of quality feedstock planting material, and unclear land tenure systems. Other challenges include lack of multidisciplinary and holistic policies that encompass the areas of environment, agriculture and the community, in addition to lack of local knowledge on liquid biofuel production. Further, the biodiesel development in eastern Africa has not been sustainable and was not successful because of lack of previous experience; lack of well-known biodiesel crops, lack of technology, insufficient research on many aspects of the industry, insufficient land suitability analysis, and not involving local people, but with more reliance on government efforts. The collaboration of smallholders, private sector and government in liquid biofuel production was very low, therefore constraining sustainable production of biofuel. The involvement of foreign investors in eastern Africa for the production of biodiesel was based on impracticable dream that took place without the knowledge of the need of local people, the type of soil and climate and crop type. The local people were key actors to catalyse biodiesel development activities, because their experience and interest were crucial. Some of the coping mechanisms to contain these problems include facilitating access to credit from financial institutions like banks, as well as national governments providing incentives such as tax reduction and subsidies, provision of enabling policies, friendly regulatory frameworks, and active political support.

C6. Bioethanol production from sugarcane molasses in eastern Africa is viable for distillers over 100,000litres per day. The viability and competitiveness of biodiesel production requires highly productive feedstock per unit area and per unit time; much higher than the currently utilized feedstocks such as jatropha, croton, castor, and oil palm. Developing techniques for producing ethanol and biodiesel from second generation feedstocks of residual biomasses (lignocellulosic type) has great potential for strengthening/building a circular green economy without competition for land between feedstock production and other food and livestock feeds.

C7. Biodiesel and bioethanol production at smallholder farm level has been less practiced in eastern Africa, making investors coming for large scale production of liquid biofuel unable to sustain their production, because the local farmers have not been sufficiently trained on these kinds of investments.

6. LESSONS LEARNT

L1. The establishment of liquid biofuel development could be based on the already available technology and local practices, and to the extent possible with the involvement of smallholder farmers.

L2. Selection of land and feedstock for liquid biofuel production require the consultation of local people, local experts, and researchers.

L3. The diversification of energy sources, improvement of energy security and saving of foreign exchange through import substitution of fossil fuels will only be possible if the biofuels produced and generated in the countries are mainly for local consumption and the surplus exported to generate foreign currency. This is possible if there is good supporting infrastructure for smallholder farmers to grow agro-energy crops and process those using local processing plants, something that is still missing in the countries.

L4. Eastern Africa has considerable potential for the production of biofuels if the industry is well managed and fully involves smallholder farmers. This could contribute to creating new employment opportunities, sustainable source of income in rural areas, and enhance circular green energy security. These benefits combine to address concerns of rural women who are involved in collecting firewood as a major source of energy and practicing subsistence farming that has not helped much to improve their livelihoods.

L5. The foreign large-scale plantations of biofuels in eastern Africa might not always be a suitable mode of production, since they will involve taking up considerable land; something, if not done properly, could create considerable pressure on land soon that could lead into social conflicts as the population grows, and even lead to food insecurity.

L6. Sustainable liquid biofuel production in the countries depends on improved crop varieties, efficient production of technologies, and storage infrastructures at factories.

L7. The failure of the liquid biofuel investments promoted development of policy direction towards research on biofuel crops and experimenting with mixed models of small- and large-scale production of bioenergy crops on degraded lands. It also saw smallholders' initiatives on growing bioenergy crops, and on use of communal lands that were not used for grazing and food crop production for production of biofuel feedstock crops.

7. RECOMMENDATIONS

R1. Liquid biofuel production in eastern Africa countries is limited to jatropha, croton, sugarcane, sweet sorghum, and cassava; however, there are other several feedstocks that the region can promote. Ethanol production is the most common liquid biofuel and predominantly produced from sugarcane molasses. It is important to use of locally produced multipurpose crops for oil extraction. It is, also critical to investigate advanced or second-generation biofuel production technologies such as residual lignocellulosic biomasses, agricultural residues or non-food parts of current crops, stems, leaves and husks, as well as other crops that are not used for food purposes (non-food crops), including switch grass, grass, jatropha, whole crop maize, miscanthus and cereals, and industry wastes such as woodchips, skins and pulp from fruit pressing.

R2. Sustainable production and use of liquid biofuels require policy and regulatory support such as subsidies on acquiring advanced technology for lignocellulosic ethanol, pyrolysis biodiesel, and pyrolysis oil production, in addition to well-structured institutional arrangements. Feedstock producers and processors need contractual agreements with guaranteed markets.

R3. Enactment of biofuels policy, where it does not exist, and its adoption to give the sector a legal framework to operate is highly needed. Small scale pilot biodiesel production units could be established in the rural areas already having biodiesel feedstocks to act as a demonstration site to the rural communities and a market for their produce which currently has no market.

R4. A more forceful implementation of low carbon policies would position the transport sector better to reach 2DS requirements in the near decades by using liquid biofuels, and eventually reduce deforestation.

R5. Since the liquid biofuel market cannot completely replace conventional fuels use soon incentives are crucial to make commercially driven biofuel successful, as well as formulation of common polices by neighboring countries on pricing and blending to prevent cross border fuel smuggling.

R6. More research should be done on sweet sorghum as a biofuel’s feedstock due to its duo benefit of enhancing food security from seeds and economic benefits to the farmers from stem that produce sugar.

R7. Use of biodiesel in rural areas not connected to the electricity grid to generate power for pumping water, lightning, and for use by SME’s like posho mills in Tanzania should be encouraged to promote rural development.

R8. Involvement and close co-operation between all stakeholders (government ministries, farmers, alcohol producers, oil marketing companies and car manufacturers), both for the elaboration and the implementation of the liquid biofuels projects is highly desirable.

R9. Establishment of long-term, stable and clear policies, together with regulations and incentives are necessary in order to guide blending (as one option to support the development of biofuels) and starting with low blends to avoid necessary vehicle changes.

R10. It is necessary to institute initial price guarantee for biofuels (e.g., through fixed prices by the government) to secure return on investment in the biofuels sector; protection of local manufacturers against cheap biofuels imports in order to facilitate the build-up of a strong national biofuels industry; and establishment of revenue sharing mechanisms to ensure that small-scale farmers benefit from production of biofuels.

R11. Land allocation to investors must be facilitated by national governments and properly documented.

R12. Since there is insufficient information on productivity of bioenergy crops in eastern Africa, research into productive bioenergy crops could guide selecting best varieties of biofuel crops which are high-yielding, and of disease-and-pest resistant clones adapted to the countries soil and climate conditions.

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Contact us at:
African Forest Forum
P.O. Box 30677-00100 Nairobi GPO KENYA
Tel: +254 20 722 4203 Fax: +254 20 722 4001
E-mail: exec.sec@afforum.org
Website: www.afforum.org