Current Status and Future Potential of Liquid Biofuel Production for Green and Circular Economies in Eastern Africa: A Case Study of Ethiopia, Kenya, and Tanzania

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Abstract

There is growing global interest in the use of liquid biofuels across various sectors as part of sustainable bioeconomies. This study examines the status, trends, and potential of liquid biofuel production in the Eastern African countries of Ethiopia, Kenya, and Tanzania. Using field and factory visits, interviews, and discussions with key stakeholders, the suitability of different land areas for biofuel crops was assessed to be Ethiopia has 31 million hectares suitable for croton plants and 0.7 million hectares for sugarcane; Kenya has 18.6 million hectares, and Tanzania has 85.64 million hectares suitable for sweet sorghum. Annual ethanol production between 2020 and 2022 was 24.25 million liters in Ethiopia, 8.25 million liters in Kenya, and 1.4 million liters in Tanzania. Lignocellulosic residues were identified as promising feedstocks, with potential annual production capacities of 8.2 billion liters in Kenya, 10.8 billion liters in Tanzania, and 35.7 billion liters in Ethiopia. Microalgae also emerged as a viable alternative feedstock. Biofuels, whether pure or blended, reduce emissions by 10–90% compared to fossil fuels. However, investment in first-generation feedstocks has faced setbacks due to inadequate planning and limited involvement of smallholders. The study concludes that increased awareness, improved productivity, adoption of high-yielding varieties, and development of local technologies are essential to advance biofuel production in the region.

Keywords: Biodiesel, Blending, Emission, Ethanol, Potential Biofuel, Sugarcane Molasses

Introduction

Liquid biofuel production and utilization continues to receive global attention because of the need to reduce emission caused by fossil fuels, to supply alternative energy sources due to depletion of fossil fuel reserves and to promote growth in local economies. The reliance on fossil fuel has increased energy-related CO_2 emissions from 277ppm in 1750 to 422.5ppm annual average in 2024

(https://www.carbonbrief.org/analysis-global-co2-emissions).

Globally, about over 2.7 billion people will have no access to clean cooking energy by 2030 (OECD/ IEA, 2017). According to IEA (2019), 850million people globally and over 550 million in Africa (48% of the world) have no access to electricity (OECD/IAE, 2017), showing deep disparities with the promise of energy for all, as the pace of renewable-driven energy transitions is slow. In this regard, the Paris Agreement states 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.

The main commercialized transport liquid biofuels made from biomass materials are bioethanol and biodiesel, commonly produced from sugarcane or corn and soybean or palm oil. The global market shares of biofuels in 2017 were 62% (85.1billion litres) bioethanol, 26% (36.1billion litres) biodiesel and 12% (16.4billion litres) biofuels from cellulosic biomass, wastes and algae (IEA, 2019).

Circular economy (CE) is one of the solutions to overcome global sustainability challenges and deforestation through closing resource loops by regenerating, and circulating to reduce, reuse, recycle or remanufacture the output of one material to the input of the other and 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 and is one way of promoting circular economy.

For example, using the blend of different amounts of liquid biofuels, mainly bioethanol and bio-diesel as alternative fuel, with conventional fuel is an important option to reduce petroleum fuel consumption and holds potential to reduce GHG emissions. Biofuels are reported to have the capacity to reduce Greenhouse Gases (GHG) emissions by 10–90% relative to fossil fuels (Kartha and Larson, 2000). Biodiesel reduces emissions of carcinogenic compounds by as much as 85% compared with petro-diesel (Yage *et al*., 2009). Transport sector emission estimated in Ethiopia, Kenya and Tanzania in 2020 and 2030 in business as usual is 10 and 26; 10 and 19; and 8 and 17 $MtCO_2^e$. At the low carbon level the emission of Ethiopia, Kenya and Tanzania in 2020 and 2030 is 8 and 19; 7 and 12; and 7 and 12 of CO_2^e , which could be achieved by using liquid biofuels.

Solid biomass and petroleum fuels emit GHGs, which can be substituted by liquid biofuel. In eastern Africa, families are expected to switch to hydroelectricity as a cheaper and cleaner alternative. However, hydroelectricity production in open water storage is influenced by climate change while energy from biomass with cell bound moisture is less influenced by climate change. 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 countries made investments in green energy including liquid biofuel since 2007. 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 soil and climatic conditions. Several studies indicate the existence of enough arable land in Africa both for food and bio-energy feedstock production (IIASA/FAI, 2002). Some African countries have biofuel strategic plans, with some having allocated 10-20.6% of their land to energy crops. The evolving picture is one of an unclear development of the biofuel industry on the continent; therefore, it is important to understand the status of the biofuel industry and what guidance individual countries can use in developing policies and regulations to guide the industry. 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 energy.

Accordingly, the present study investigated the scale of production of liquid biofuels, potential of sugar cane factories and lignocllulosic biomass in the production of ethanol, reduction GHG in order to facilitate planning the growth and development of local, national and sub-regional liquid biofuel sector and circular green economy.

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 were shown in Figure 1.

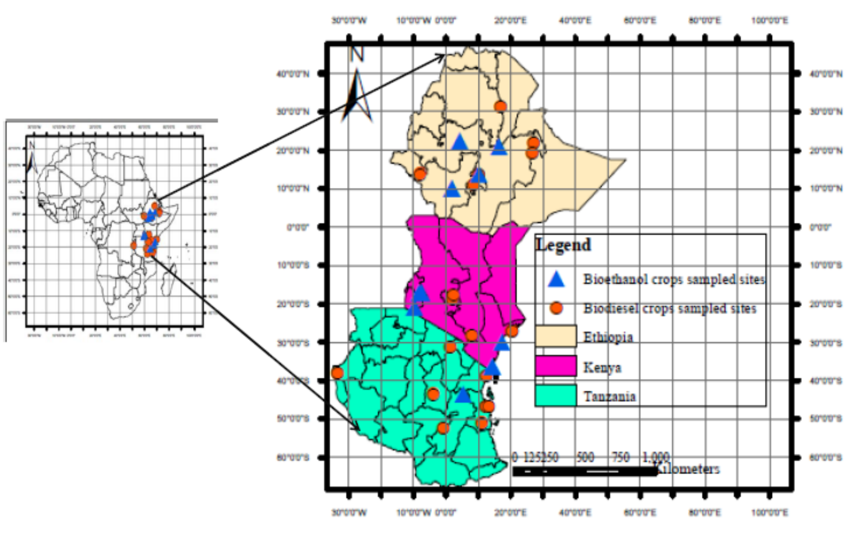

Figure 1: Location of the field study sampled areas

Study Areas and Data Collection Procedures

Different regions of Ethiopia, Kenya and Tanzania were assessed to interview processors of feedstock, research institutions and universities, relevant lead agencies, national and international NGOs purposively.

Key informants and focused groups of 15, and 11 in Ethiopia, 23 and 11 in Kenya and 17, and 13 in Tanzania, respectively were interviewed about the past activities and current status of biofuel by using pretested, structured and semi-structured questionnaire.

The soil, rainfall, temperature, elevation and land use/ landcover conditions of biofuel crops sites and land suitability analysis was obtained from literature. The interview responses obtained from the small holder farmers and their associations was triangulated with the respective district development agents and official government reports, and private sectors and the emissions were compared based on the availability of liquid biofuel from previous literature. Then qualitative data were summarized by narration and the quantitative data was analysed by descriptive statistics.

Results and Discussion

Liquid biofuels commonly available in eastern Africa were bioethanol and biodiesel produced from higher plants including sugarcane, sweet sorghum, cassava, jatropha, castor and croton. There was also ongoing research on the identification of microalgae for biodiesel.

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

Land Suitability for Production of Liquid Biofuel Crops

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 countries of Ethiopia, Kenya and Tanzania has abundant suitable land (Table 1) that can be used for major biofuel crops, such as jatropha, castor, croton, cassava, cotton, sweet sorghum, oil palm, and sunflower. However, the productivity of food and biofuel crops per unit area and time is low.

Areas with annual precipitation 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 1000mm, 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.

Table 1: Land suitability for different biofuel crops in eastern Africa countries of Ethiopia, Kenya and Tanzania

Biofuel crop type	Ethiopia*		Kenya**		Tanzania***	
	Area (million ha)	Area (%)	Area (million ha)	Area (%)	Area (million ha)	Area (%)
Jatropha	17	13.2	14.9	26.2	>19.9	>22.59
Castor	33	24.8	15.9	28	>19.9	>22.59
Croton	31	23.8	3.52	6.2	>19.9	>22.59
Cassava	38	28.5	6.6	11.2	19.9	22.59
Cotton seed	6	5.2				

Sweet sorghum	5.4	4.1	18.6	30.6	85.64	97.2
Sugarcane	0.7	0.5	1.3	2.6	1.74	1.97
Oil palm (tall)					1.41	1.6
Oil palm (compact)					1.7	1.93
Sunflower					78.93	89.58

*(Sources: * EMoMPNG, 2018; ** Muok et al, 2010; Kassam et al., 2012)*

In Ethiopia, the potentially available land for bio-energy oil crops has been estimated at 23.3 million hectares (CRGE, 2011) out the total 110.4million ha. However, based on rainfall, temperature, soil type and altitude it was estimated that about 17 m ha (13.2%) suitable for jatropha and 31 m ha (23.8%) for croton (EMoMPNG, 2018). Further, about 0.7 m ha (0.5%) is found to be suitable for the production of sugarcane (Table 1), and in the presence of continuous irrigation about 4 m ha is suitable. Large scale biofuel investments on land covering over 2000ha were made in different parts of Ethiopia by private investors. However, in 2021 there were no private investors for biodiesel production and all abandoned the investment.

In Kenya, the total suitable land available for biofuel production is estimated at 48.9million ha, which is 85% of the total land area. About 1.3m ha (2.6%) 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 18.6 m ha (30.6%), and cassava is 6.4mha (11.2%) (Muok *et al*, 2010). Tanzania has very large areas of land currently little used that might be cultivated to grow biofuel feedstocks. Out of the total area of agro-climatically suitable land with tillage-based production of low and high input for cassava is 19.9mha (22.59%), and sugarcane is 1.74mha (1.97%) (Kassam *et al*., 2012) (Table 1). For biofuel production, the only investment remained in 2021/22 was sugarcane production and its by product molasses for bioethanol.

Availability of Edible and Non-Edible Feedstocks for Liquid Biofuel Production

The major feedstocks identified in Ethiopia are cassava, castor, ground nut, jatropha, 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, corn, rapeseed (canola), sugarcane, sweet sorghum, and wheat.

Bioethanol Production

Bioethanol is the most common type of liquid biofuel for both transport and cooking energy in eastern Africa. Here ethanol refers to bioethanol throughout the paper. 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, cooking sector, the growing pharmaceutical and alcohol beverage industries have high demand for bioethanol. 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.), amaranth (*Amaranthus hypochondriacus* L.) and others.

There is also a number of ligno-cellulosic biomasses for bioethanol production which are different from sugarcane and sweet sorghum stem that accumulate sugars in the form of juice.

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 Metahara and Finchaa sugar factories ethanol that encountered power interruption in converting molasses to ethanol. E10 blending was adopted when there was better ethanol supply, while E5was done when supply was low.

Farmers Association, companies and government organizations were producing biofuel crops or feedstocks. However, there was no private farmer that processed biofuel for consumption. The smallholders' sugarcane is usually used for consumption as food. 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 shortage and damage to boilers. Although molasses was widely available for ethanol production, the old sugar factory and its old accessories were unable to supply sufficient steam from the bagasse and electricity to ethanol factory.

There were different NGOs working on biofuels, such as Gaia association, that supply cooking fuel to poor people and refugees. Gaia association was purchasing ethanol or processing molasses to ethanol to supply to firewood carriers to trade around Addis Ababa, instead of trading in firewood. About 20,000 to 25,000 liters of ethanol was supplied to such firewood traders in turn 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 obtained from sugar factories to substitute firewood, charcoal and kerosene. In the EMD different problems were raised including lack of waste disposal sites, power shortages and lack of molasses and then finally damaged and dismantled by the local people. Later, the feasibility of establishing small scale distillers was questioned and distillers over 10,000liter per day were recommended with 4kg of molasses for a liter of ethanol. The expansion of sugarcane for the production of biofuels has been observed at 13 sugar factories in Ethiopia, 16 sugar factories in Kenya, and five sugar factories in Tanzania. Although eastern African countries has 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).

For the eastern African region the most common feed stock 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

Table 2: Molasses and ethanol production capacities of sugar factories in Ethiopia, Kenya Tanzania

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

Kenya	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
	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	429,216	107,304,000	
	1	Kilombero Sugar Company Limited	25,000	1964/1988	142.08	1,400,000	36,230	9,057,600	Public produced ethanol in 2021
Tanzania	2	Tanganyika Planting Company L.	8,000	1973	60		15,300	3,825,000	Public no ethanol in 2021
	3	Kagera Sugar Limited	9,000	1933/1974	56		14,280	3,570,000	Public no ethanol in 2022
	4	Mtibwa Sugar EstatesLimited	6,000	1958	72		18,360	4,590,000	Public no ethanol in 2022
	5	Bagamoyo Sugar Ltd_Tanzania	10,000	2022	72		18,360	4,590,000	Public will produce ethanol in 2022
		Total			402	1,400,000.	102,530	25,632,600	

All the sugar factories in Ethiopia were owned by the state and all the cane was produced by the state except one called Wonji Sugar Factory that used the outgrowers. However, there was a plan to produce ethanol by private company in Wonji and Kesem sugar factories. Most of the factories in Kenya were privatized or in the processe of privitazation and most of the factories in Tanzania were in transition to private sector (Table 2).

The annual working times in sugar factories range from 209 to 257 days per year with average of 250days production days. The productivity of sugarcane is about 80 to 192 tons in a hectare with an overall average of 138 tons per hectare.

The consumers of the bioethanol are Government Company for fuel stations blending (99.9% alcohol with 0.1% water), for cookstove 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 is said to be a lucrative business because a number of products are obtained from sugarcane processing (Fava Nevesa and Chaddad, 2012).

In Ethiopia, fuel ethanol production was commenced in 1979, and sold to Sweden and Italy, which was interrupted because of market.

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 again in 1993 because it was uneconomical way of producing and transporting bioethanol to the market, drop in global oil prices, 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.

In Ethiopia, Kenya and Tanzania, the sugar factories producing ethanol are those that installed molasses fermenters and ethanol distillery, which were only one or two in each country. As a result, the 2019/2020 bioethanol production was 24.25 million litres/year in Ethiopia, 8.25 million in Kenya and 1.4million 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 potentially produce 108billion litres of ethanol per year, while the Kenyan 16 factories can produce 72billion and those Tanzanian five factories can produce 20 billion litres; with average of 250 working days (Table 3).

Table 3: Current and potential production of ethanol from sugarcane molasses in existing and improved technologies of sugar factories in eastern Africa countries, Ethiopia, Kenya and Tanzania

Country	Area of sugarcane (thousand ha)	Existing technology of ethanol from sugarcane molasses		Improved technology and productivity of sugar cane
		Current produc tion (million litres/year)	Potential production (million litres/year)	Potential production of ethanol from sugarcane molasses (billion litres/year)
Ethiopia	307.196	24.25	360.672	108.102
Kenya	205.513	8.25	107.304	72.320
Tanzania	58.000	1.4	25.633	20.410

(Source: Analysis of sugarcane land area-based data)

3.2.1.1 Ligno-cellulosic biomass for liquid biofuel production

In ethanol production, feedstock costs accounts to 60 to 85% of the total production cost and in biodiesel the production, feedstock costs account up 80 to 90% of production costs because of labor, food and transport costs (IRENA, 2013). Therefore, it advisable to explore cheap and more price stable biomass sources for production of liquid biofuels. The costs of lignocellulosic feedstocks such as agricultural residues, residues of first generation crops, forest woody biomass, high yielding energy crops, municipal solid wastes, and sugarcane bagasse is lower than production based on feedstocks that could be used for food or feed production. Lignocellulosic biomass is attractive feed stocks for bioethanol production because they are diverse, abundant and less costly.

Lignocellulosic ethanol is an environmentally friendly transport fuel and a key alternative to fossil gasoline. It 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. However, these bioethanol production systems are presently at a relatively early stage of optimization, whilst a number of pilot and demonstration second generation bioethanol plants are under implementation.

There are about 2.2million tons of agricultural residues in Kenya to19.7million tons in Ethiopia, as well as 24.2million tons of woody biomass residues in Kenya to 105.2million tons in Ethiopia; 3.02kilotons of sugarcane bagasse in Tanzania to 387.7 kilotons in Ethiopia (Table 4). For example, one ton of dry woody biomass produces approximately 89.5 gallons or 339 litres of cellulosic ethanol (BRDB, 2008). The ethanol from lignocellulosic biomass could be 8.2 billion litres/year in Kenya, 10.8billion in Tanzania and 35.6 billion in Ethiopia.

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 liters/year)	6.78	0.76	0.79
Ethanol from woody biomass residues (million liters/year)	35,590.21	8,187.10	10,792.09
Ethanol from sugarcane bagasse (kilo liters/year)	110.11	3.90	0.86

Imports of petroleum and its products (billion liters)	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: 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 cassava	184 litres bioethanol
1 tone of sugar cane	0.3 tone bagasse
1 tone of sugar cane	0.7 tone juice
1 tone of sugar cane	0.04tone molasses
1tone molasses	255 litres bioethanol
1 year working days	250 days

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

The full potential of molasses ethanol or lignocellulosic ethanol is higher than the imports of petroleum products of each country. For example, Ethiopia has imported nearly 4.5 billion liters of liquid fossil fuel including gasoline, jet fuel, kerosene, gasoil, and others; and spent $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 is 35.6 billion litres/year which is about eight fold of the fossil fuel imported (Table 4). Then the liquid biofuel can be used as blend or pure substitute of the import 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 liters of petroleum products in 2018 (KNBS, 2019; EPRA, 2019). The use of lignocellulosic biomass could produce 2.1billion liters of bioethanol in excess of the import (Table 4), and then additional biofuel for other energy need or for export market.

Tanzania has been importing liquid biofuel and consumed about 3.6 billion liters of petroleum products in 2020 (Faria, 2021) and lignocellulosic bioethanol potential is 7.2billion liters in excess of the import (Table 4).

The lignocellulosic biomass can also be converted to pyrolysis oil or bio-oil by heating at 400-1000°C in oxygen limited furnace or kiln and condensation of volatiles. There are also ample biomass feedstocks for bio-oil production including bagasse, hardwood and softwood, municipal, livestock and wood waste, potato skin, wood sawdust, rice husks, sugarcane waste, corn cobs and corn stover. For example, there are *eucalyptus* species of 1mha in Ethiopia, 350,000ha in Kenya, and 25,000ha in Tanzania; and agricultural residues of 19.7mtones/yr in Ethiopia (MoWE, 2012), 2.2mtones in Kenya (Republic of Kenya, 2002) and 2.3mtones in Tanzania (MNRT, 2013).

Circular Economy of Biomass and Sustainable Development

In circular economy, sustainable liquid biofuels can be produced technically from lignocellulosic biomass. The transition from traditional bioenergy to second generation biofuel production from lignocellulosic biomass to liquid biofuel (GBEP, 2011) called bioethanol and biodiesel are examples in circular green economy. The residues of agricultural harvest and food processing can be used partly for soil amelioration, while 25-50% can be used for livestock feed and for liquid biofuel production. As food production grows for the growing population, the projected agricultural residues for bioenergy will also grow **(**FAO, 2015). It was 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 could provide feedstocks for liquid biofuel (FAO, 2015).

Biodiesel Production

Field observations and interviews made on stakeholders related to biofuels revealed that the demand for vegetable oil for food is very high. Therefore, it could be expensive to use of oils from edible seeds and vegetables in eastern Africa for liquid biofuel production. These feedstocks are more important for food security in the region. Moreover, there was no viable production and processing of biodiesel in eastern Africa countries studied.

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 process was lengthy and was not well coordinated. In Feb. 2021, there was no investment on biodiesel production, and all licensed ones had either stopped the biofuel investments or changed the 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 commonly used feedstock for the production of biodiesel was jatropha. In sampled study sites in Ethiopia, castor and ground nut are common in Harar-Fedis, sugar cane 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. Seed production was commenced, oil extracted, biodiesel and soap manufactured at laboratory trial scale. The initial fund to plant seedlings of jatropha was obtained from the national project fund, however, the whole activity was terminated when the project phased out (Global Market, 2008).

The lack of finances, lack of market and poor technical capacity of the biodiesel production project in Ethiopia led to the termination of oil, soap and biodiesel production and farmers frustration. What remained was the degraded land that was rehabilitated due to jatropha plantation (Figure 2).

Figure 2: Rehabilitated jatropha planted degraded land in Bati woreda, Ethiopia

There were different types of ongoing research activities 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. However, there were different administrative and financial constraints in biofuel research organizations as a result, the biofuel research was not well organized and had no proper ownership by an institute.

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

- Lack of modern equipment to process and produce ethanol and oil,
- Lack of high yielding variety crops and no breeding effort on biofuel crops, for example, the yield obtained was very low, as low as 4 kg seed of jatropha that resulted into 1liter oil;
- Improper site selections as potential suitable areas for biofuel crop production,
- Lack of awareness creation to consumers on bioenergy crops,
- Inability to afford access and use first generation liquid biofuel crops.

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 regional states like Southern Nations and Nationalities People Region (SNNPR), biofuel sector of Ethiopia was coordinated at Federal Ministry of Energy at directorate level, and Federal Level Round Table for Sustainable Biofuel Production (RTSBP) strategy was developed to produce airplane liquid biofuel. 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 of Ethiopia with respect to different technological aspects and agronomic practices, respectively with proper feedback to each other. Proper follow up and interface in productivity, marketing and quality assurance management are highly required. In Ethiopia there was biogas agency and the experts recommended the formulation of a similar agency for liquid biofuel in regions, zones and districts.

Some Experiences from Kenya

In Kenya, the flurries of 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 and established 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.

Some Experiences from Tanzania

In Tanzania, jatropha was widely planted for the purpose of producing biodiesel. However, during the study period there was no production of biodiesel. The earlier production, which 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.

There was wide area of oil palm plantation (Figure 2) for the production of oil to increase the production of cooking oil and thus scaling down the importation. However, local authorities stated that, the domestic production constitutes less than 2% of the country's consumption.

Figure 3: Oil palm farm in Tanzania and Kenya

Microalgae Production

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

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 for the production of biodiesel (Spolaore *et al*., 2006; Chisti, 2007).

Research conducted at Metahara Sugar Factory in eastern Ethiopia, revealed that the wastes in sugar production was used for microalgae growth that produced biodiesel, upgraded biogas, and bio-fertilizer at 188 tons/year, 1,974,882 m^3/year and 42 tons/year, respectively (Zewdie and Ali, 2020).

Some microalgae strains are capable of generating 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 per day, 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.

Greenhouse Gas Emission Reduction Potential of Liquid Biofuel

There are projections of emission in 2030 based on 2010 levels. With the aim of net zero emission in 2050°C, transport emissions in 2030 must be below 2010 levels in order to be in line with 2 degree centigrade scenario (2DS).

The use of ethanol for cooking at household level reduces emissions of 99.8% of particulate matter created by burning solid biomass in three stone stoves; 91.0% of that created by wood/charcoal Rocket Combo stoves and 95.1% of carbon monoxide created by charcoal stoves (Table 5). .

Table 5: Emission reduction of the 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 firestoves; StoveTec Rocket, charcoal Jiko and wood/ charcoal Rocket Combo (MacCarty *et al*., 2010) (Table 6). Using biodiesel also reduces enduse emission by 38.90 to 39.42% when compared with firewood and kerosene at household level (Fekadu *et al*., 2019).

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. The conversion of CH_4 to CO_2 by reducing the rate of decomposition reduces emission. 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 tonnes GHG, based on the proper accounting of vegetation's live period of at least five years (EMoMPNG, 2018). In Bati woreda of northern Ethiopia, jatropha plantation as live fence stored 137.36 $tCha^{-1}$ and on degraded lands about 5.41$tCha^{-1}$, totalling 142.77$tCha^{-1}$ (Teshome *et al*., 2013). 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).

In Ethiopian climate resilient green economy strategy (CRGE), the transport sector has green growth initiatives that include blending biodiesel to the diesel, ethanol to gasoline, 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 Ethiopian 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. The achievement of the abatement potential require 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 lignocellusic biomass is sufficient if second generation biofuel technologies are employed.

The frequently practiced bioethanol production has 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, sulfur) for soil enrichment, herbicides, and fungicides to protect disease and insect pests. The highest emission in sugarcane ethanol production occurs during cultivation of cane, about 190 gCO_2^e/liter of bioethanol (Table 6).

Table 6: GHG emissions based on Life Cycle Analysis (LCA) of sugarcane to bioethanol

Stage in life cycle	Unit of measurement	Stage in life cycle	Emissions (%)
Sugarcane cultivation	190 gCO_2^e/L of bioethanol	Cultivation	70
Nitrogen (N_2) fertilizer – 52% of cane emissions	98.8 gCO_2^e/L of bioethanol	Milling/Ethanol production	4
Cane milling for bioethanol production	9.19gCO_2e/liter of bioethanol	Transportation	8
Net GHG emissions are 270.87 gCO_2^{e}/litre of bioethanol for complete life cycle chain. Nitrogen (N_2) fertilizer contributing ~37% of total emissions		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 emit different levels of GHG. The application of bagasse residues decomposed, and chemicals fertilizers used increase GHG emission of soil. For example, application of urea increases emissions of CO_2 and N_2O from soil (Serrano-Silva *et al*., 2011). However, the different by-products like bagasse in sugar production, vinasse and other organic wastes in ethanol production, can be converted to biogas to get organic fertilizer and therefore, reduce emissions.

Figure 2: Sugarcane farm at maturity stage, and harvesting

It is generally believed that biofuels made from grain crops produce as much carbon emissions as fossil fuels in cases of occurrence of deforestation (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 fossil fuels as 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 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; with abatement potential of 1.64 $MtCO_2^e$; adoption of low carbon and efficient transport including biodiesel with abatement potential of 1.2 $MtCO_2^e$ The other mitigation options are found in the energy, transport, industry, agriculture, forestry sectors, and improved waste management.

Tanzania commits to reduce greenhouse gas emissions economy-wide between 30 to 35% relative to the Business-As-Usual (BAU) scenario by 2030 (138 - 153 $mtCO_2^e$) by promoting clean technologies for power generation and diverse renewable sources such as geothermal, wind, hydro, solar and bioenergy (URT, 2021).

Investment on Liquid Biofuel Production in Eastern Africa Region

Africa had very limited experience of producing liquid biofuels (Batidizirai and Johnson, 2012). At the global level, the total contribution of biofuels from Africa remains insignificant (IEA, 2011), despite the continent's vast areas of land that are climatically suitable for biofuel feed stock production (Watson, 2010). From total primary energy supply in continents in 2019 including coal, oil, gas, nuclear and renewable energy sources, African continent has the highest renewable energy share (47%) due to hydropower and traditional biomass use for heating and cooking (WBA, 2022). As shown in Table 7, the biomass production in 2019 was 16.0 EJ but the liquid biofuel was almost nil in 2019 (WBA, 2022) which indicated lack of conversion technology, among many other factors. Currently, a large number of African countries have developed biofuel policies that envision a contribution of biofuels to the national energy mix (Mitchell, 2011) in order to substitute the petroleum imports and to contribute to rural upliftment (Diaz-Chavez, 2013).

Table 7: Domestic supply of biomass and liquid biofuel in continents in 2019

Continent	Solid Biomass (EJ)	Share renewables from total primary energy supply in continents (%) in 2019 (WBA, 2022)	Liquid biofuels (EJ) in 2019 (WBA, 2022)
Africa	16.0	47%	0.00
Americas	8.1	14%	3.00
Asia	19.3	13%	0.62
Europe	4.7	12%	0.63
Oceania	0.22	12%	0.01
World	48.32	98%	4.26

Some Pitfalls in the Past Biofuel Projects in Ethiopia, Kenya, or Tanzania

National governments of Ethiopia, Kenya, and Tanzania allocated large areas of land for biofuel production, but appropriate land use policies and modern productive agricultural techniques are still in early stage. In 2010, there were about 82 registered biofuel investors in Ethiopia since 2006, mainly for the cultivation of energy crops for biodiesel production (Gebreegziabher *et al*., 2014). The land was allocated by federal investment offices, regional land administration offices and even by the energy ministry that confused the implementation and coordination. Moreover, the capacity of investors was not screened (Gebreegziabher *et al*., 2014). Then many investors retreated back before the implementation phase and those that started operations showed very sluggish progress and finally terminated.

In Kenya, there was a number of registered biofuel investors. The decreasing yield of agricultural crops like maize, increasing woody biomass deficit, increased food and feed demand, inaccessible marginal/degraded land, poor productivity of jatropha in the Tana Delta area in 2009, resistance from the local environmental NGOs, conflicts between locals and governmental corruption reduce the interest towards biofuel crop production (Krijtenburg, and Evers, 2014).

In Tanzania, 37 companies sought land for biofuel production in 2008 and 20 companies had requested land for commercial biofuel production in 2009, with land area 30,000 ha to two million hectares of land (Kamanga, 2008).In Tanzania, the issues of energy matters are handled by different departments such as forestry, health, and works, among others (Camco Clean Energy, 2014). The Tanzania liquid biofuel guideline (MEM, 2010) proposed to ensure no forced displacement of people for biofuels development, encouraged out-growers model or hybrid model (plantation and out-growers schemes), form associations/cooperatives of out growers, local people involvement in the processing and value adding activities, the processing of the final liquid biofuel within the area or country where the feed stock was produced. Although sustainable liquid biofuel development was formulated in Tanzania (MEM, 2010) with land tenure of 25 years or less depending on the crop characteristics, a decade or less of biofuel investment in the country showed that as there was lack of adequate domestic institutions that resulted in land-grabs, land-use conflicts, corruption, technical challenges, lacking infrastructure and resource trade-offs (Hansson *et al*., 2019).

According to Wiggins *et al*. (2011), liquid biofuel policy in eastern Africa has lagged behind the recent surge of investors seeking land as there was no clear framework for the development of biofuels. The eastern Africa region requires national regulatory liquid biofuel frameworks, so that the land use is not driven by foreign investors and the local poor people and subsistence farmers are not driven off from their land.

Biofuel investments in Africa failed on all counts because of different reasons. (1) the biofuel crops such as jatropha and castor which were supposed to be planted in marginal lands performed poorly (poor productivity) in areas with low rainfall or low nutrient soil, to the extent that it is no longer being grown in such areas originally developed. These resulted in poor yields just a fraction of those expected by companies and farmers alike. (2) Biofuel companies in some parts of Ethiopia were paying farmers lower prices per unit of biofuel jobs done than they would earn from growing traditional food crops, or failing to pay farmers at all. (3) Biofuel feedstock produced in Ethiopia was being exported for processing and sale in European and Asian markets, which was not in any way in agreement signed to address the government’s stated need for energy security. (4) At policy level the government also failed to undertake the monitoring and regulation required to prevent negative socio-economic and environmental impacts. Then the biofuel investments of Africa's Biofuel rush resulted in extensive land grabbing, deforestation and hunger and it was a disaster for Africa's communities and biodiversity, and a failure for farmers and, for governments (ABN, 2010). The investment was said to be poorly planned and exploitative commercialization schemes (Chinigò , 2022).

UN (2007) proposed different policies for small scale liquid biofuel production including market push policies (increasing biofuels supply), market pull policies (increasing biofuels demand), and mega policies (feed-in tariffs for a long-term price of liquid biofuels) and renewable portfolio standards (purchase liquid biofuels in the market). Moreover, taxation of fossil fuel and subsidies to liquid biofuels did not motivate the market for liquid biofuels in eastern Africa because of lack of focus on small holder farmers. The investment was based on large scale plantation by displacing forest or other vulnerable ecosystems. Sustainability of rural liquid biofuel projects requires gender-based community participation in planning process, provision of seeds and other required inputs and effective use of new income generating opportunities (Hansson *et al*., 2019).

Although there was no country in eastern Africa region that developed a biofuel production policy, except Kenyan biodiesel strategy, many countries in the region had allocated land for biofuel crops production and plants the crops. Therefore, appropriate policy based on sustainability indicator criteria of Global Bioenergy Partnership (GBEP) on liquid biofuel that solve the main challenges of the region including achieving food security and energy security are required (GBEP, 2012). Moreover, appropriate compensation and establishment are required before displacement of poorer people from land. Productivity of land improvement is highly important instead of destruction of forests and important ecosystems like wetlands.

Comprehensive Framework for Liquid Biofuel Production in Eastern Africa

The Eastern Africa can benefit from alternative model of biofuel project development as optimal solutions that include stakeholder engagement adjusted strategies, policy recommendations, and technology integration that address local conditions of climate change, energy security, food/ feed security, biodiversity conservation, and environmental pollution (Table 8).

Table 8: Alternative model of biofuel project development for optimal solutions

Effects of liquid biofuel products and services in	Optimal solution
Climate change	Governance policies are required for appropriate landuse designation to avoid unsustainable exploitation of natural forests for biofuels; Sustainable biofuel production, sustainable forest management and sustainable agriculture (food security) should be designed at integrated policy level with clear understanding of environmental, economic and social issues
Energy security (reducing imports of fossil fuels)	Sustainable planting, management and harvesting of biomass. Appropriate supply of soil nutrient and protection from crop related disease or pest infestation, and improved land management techniques and practices are required for both food and bioenergy production

Food/ feed security	Zoning of agricultural or forestry land use for biofeed stock production should be based on edaphic and hydrological limitations (Lal, 2008); land suitability determination using areas most suitable for agriculture or forest production (Dale *et al*., 2011); planting biofuel crops in degraded lands instead of pristine ecosystems and food croplands has sustainability and food security roles (Stoms *et al*., 2012)
Local sustainable development and innovation	The availability of sustainable biomass and efficient, low polluting, cost effective conversion technologies and the societal factors on how biomass is used, scaled up and deployed at the appropriate level by understanding of the social, economic and political aspects. Since forestry and agriculture policies are interdependent, harmonizing them for the sustainable production and supply of bioenergy, there should be national and regional integrated forestry, agriculture and bioenergy governance policies that address the full valuation of forest goods and services, opportunity costs of forestland and cropland conversion and alternative cropping systems, law enforcement, institutional capacities, safeguarding local user rights and land tenure arrangements are highly important (Souza *et al*., 2015).
Biodiversity conservation	Native vegetation should be retained within agricultural or forested landscapes; it is important to produce domestic species and conserve wild species (Verdade *et al*., 2014). Sustainable land use, zoning principles and enforcement to impede the conversion of ecologically significant, threatened and sensitive areas for biodiversity. In forest covered areas, financial incentives are required to reduce carbon emissions from deforestation and forest degradation (REDD) (Visseren-Hamakers *et al*., 2012).
Environmental pollution	Partial or full use of perennials feed stocks, using alternative rotation systems, reduced tillage, reduced use of fertilizer without cultivating riparian buffers and riverbanks. Leaving agricultural residues on the field reduces erosion (Smeets *et al*., 2008).

There was limited research and development on local liquid biofuel technology in eastern Africa evidenced by the absence of small scale development. No one can be blamed for the failure or lack of small scale biofuel development because the approach of liquid biofuel development in 2007 African biofuel strategy was top down, where countries that face climate change and fossil fuel fluctuating price initiated the interest in liquid biofuel. It was hardly possible for local people that use traditional solid biofuel, firewood, to shift to liquid biofuel without training and availability of inputs. Literature reviews showed the lack of National/ regional research centers that focus on small-scale biofuels technologies (Sulle, and Nelson, 2009). Integration of local finance and microfinance institutions that understand local markets, conditions, and clients and additionally engage international institutions, like multilateral and bilateral donors for sustainability of liquid biofuels is important. The carbon financing of small-scale liquid biofuels projects has not been explored in eastern Africa, however, improved solid biomass stoves and afforestation practices were conspicuous for clean development mechanism (CDM). Biomass Energy Strategy (BEST) for Ethiopia, Tanzania and Uganda were prepared around the year 2013 as action plan on biomass, however, further research is required on the use of the biomass for liquid biofuel production, selection of productive variety bioenergy crops and the use of advanced biofuel, and lignocellulosic ethanol and pyrolysis bio-oil.

Conclusion

- The eastern Africa countries have large areas of land to produce different biodiesel and bioethanol. The most common and potential feed stocks 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 small holders' farmers in eastern Africa have not been introduced at the required commercial scale.

- 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 promotes 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 remains slow.

- The production of liquid biofuel especially biodiesel investment ceased in 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, and when such support waned the production stalled.These countries have sugar cane factories producing ethanol from molasses intermittently, and in insufficient quantities to support significant blending with fossil fuels to supply to the transport sector.

- The farmers were not benefited from the liquid biofuel investment at the end and lost trust on biofuel development agents as responded in Ethiopia.

- In the period 2017-2021, the production of ethanol in the eastern African countries studied were from one or two sugar factories in each country. 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 conversion of molasses to 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 amount to supply fuel that substitute very significant quantities of imported gasoline. At the existing technological condition, annually the Ethiopian sugar cane factories can produce 108 billion litres of ethanol, the Kenyan 72 billion and the Tanzanian 20 billion with average of 250 working days. However, the factories were not producing bioethanol based on the full capacity of molasses produced because of old distillers, damaged boilers and interrupted power supply. The current annual production of ethanol is 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 development to produce ethanol from lignocellulosic biomass and sugar cane bagasse processing, the total bioethanol production can be 8.2 billion litres/year in Kenya, 10.8 billion in Tanzania to 35.7 billion in Ethiopia, which is higher than their annual imports of petroleum. The potential production of ethanol from lignocellulosic biomass shows the presence of extra feedstock for the production of ethanol in eastern Africa countries. However, the technologies available to convert solid biomass to liquid biofuel are not widely distributed, which requires development of the capacity of human and laboratories.

▪ The establishment of liquid biofuel development needs to start from the already available technology in local areas local practices and if possible from small holder farmers.

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

▪ . 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 used 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.

▪ . Eastern Africa has a huge potential for the production of biofuels if the industry is well managed and fully involves smallholder farmers. 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.

Recommendations

▪ Liquid biofuel production in eastern African countries is limited to jatropha, croton, sugarcane, sweet sorghum and cassava; however, there are other several feedstocks that the region can promote. It is also critical to investigate advanced or second generation biofuel production technologies such as residual lignocellulosic biomasses such as 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, including switch grass, grass, jatropha, whole crop maize, miscanthus and cereals, and also industry wastes such as woodchips, skins and pulp from fruit pressing, etc. Moreover, the current technology being used in the region is very elementary. Then fundamental production technologies and storage infrastructures at factories on improved crop varieties should be practiced.

▪ Small scale pilot biodiesel production units need to be established in the rural areas already having biodiesel feedstocks to act as a demonstration site to the rural communities and also a market for their produce which currently has no market.

▪ The emission reduction aiming at low carbon policies must be scaled up in such a way that reduces deforestation and biofuel integrated system. 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.

▪ The interviewed people recommended the use of locally suitable and multipurpose crops for oil extraction. Castor was not known locally, then the agronomic and utilization technique was unknown by the local people. The top down approach used to implement the biofuel investment became unrealistic because it did not consider the interest of local people and the need of local environment.

▪ Burning sugar cane leaves and tops emits smoke that affects the local people. In green sugar cane 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 should be used for soil amelioration.

▪ The sugar factories are using wastes of sugarcane crushing for soil amelioration, which naturally have high rate of decomposition to give off methane. Then it is advisable to construct biogas technologies so as 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 biodiesel production.

▪ Excess biofuels should be produced on the available land and feedstock for local consumption and for export since there is a big local and international market in times of climate change.

▪ Land allocation to investors must be documented with subsequent reparations in case of failure or closure of the venture.

▪ There is insufficient information on productivity of bioenergy crops in eastern Africa. Then different forestry and agricultural stakeholders should play roles in searching productive bioenergy crops in collaboration with agricultural sectors. Selecting best varieties of biofuel crops which are high-yielding, disease-and-pest resistant clones adapted to the countries soil and climate conditions is highly important. For eastern African dry lands jatropha (J. curcas), croton (C.megalocarpus), sweet sorghum (S.bicolor), and sugar cane (S. officinarum) and others research on the amount of oil and sugar content requires collaborative effort of educational and research institutes. Sweet sorghum should be widely used due to its duo benefit of enhancing food security from seed and biofuel benefits from the stem.

Conflicts Of Interest

There is no conflict of interest.

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