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REVIEW

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Potential markets and policies for sustainable liquid biofuel production with emphasis to Eastern Africa countries: a review

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Abstract

Background The production of liquid biofuel in Eastern Africa countries has the potential to play an important role on the global biofuel markets in the coming years, because transportation fuel demand is expected to grow. Despite the presence of suitable environmental conditions for bioenergy crop cultivation in Eastern Africa, liquid biofuel production has been restricted by different factors, including market situation and government policies. The objective of this review is to evaluate the potential markets, policies, strategies, and plans for liquid biofuel production in some Eastern Africa countries, including Ethiopia, Kenya, Sudan, Tanzania and Uganda.

Main text Over 64 scientific articles and reports published between 2002 and 2023 related to liquid biofuel production market and policies were collected from internet search engines and unpublished grey literatures and reviewed. Since liquid biofuel production was in early stage of investment in Eastern Africa countries by 2020, all the countries showed similar restrictions. It was found that the global market demand for liquid biofuel increased after 1980s. For example, although Ethiopia started bioethanol production in 1950s, the production was discouraged by the lack of a market. Biofuel trade is globally determined by the biofuel policies of industrialized countries, which are mainly driven by the willingness to reduce emissions and to tackle volatile fossil fuel prices. Eastern Africa liquid biofuels has a number of market openings, including rural domestic use, substituting fossil fuel imports, and supplying the European market. There are also attractive legal conditions and political willingness to invest in the production of liquid biofuels. However, institutional weaknesses hindered the possibility to coordinate liquid biofuel production. The lack of adequate domestic institutions, coordination mechanisms, and robust monitoring resulted in land-use conflicts, corruption, and technical challenges. Appropriate policy measures are required to local land use determination, selection of appropriate type of bioenergy crops, and biofuel processing types and scales. In particular, small and large-scale biofuel production projects are required to include biofuel production in the conventional agricultural farming practices.

Conclusions Good governance is highly important for bioenergy crop production, liquid biofuel processing and consumption in the whole liquid biofuel value chain. Moreover, it is important to exchange good practices through cooperation, including—but not limited to—intra-African countries, which would accelerate the learning process and the deployment of effective measures and mechanisms. There should be biofuel value chain upgrading

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to overcome fragmentation and inconsistency of measures; match-making between demand and supply at domestic, intra-African, and internationally with proper public awareness creation.

Keywords Liquid biofuels, Eastern Africa, Market, Policy, Institutional coordination

Background

Global research has identified that a scale of transformation is required by the energy and land-use sectors to stabilize Greenhouse Gas (GHG) emissions within 2 °C rise by 2050 [1]. Global warming levels greater than 2 °C will damage global biodiversity, natural ecosystems, water supply, food production and health. In 2013 and 2020 the world warmed by nearly 1 °C and 1.2 °C, respectively, compared to pre-industrial (1850–1900) revolution stage [2, 3]. There is at least one in five chance of the temperature temporarily exceeding 1.5 °C by 2024 [3]. According to the 2015 Paris Climate Change Agreement, holding the rise in world temperatures to "well below 2 °C and limit to 1.5 °C" at the end of the century cannot be attained without biofuel [4, 5]. Today, biofuel trade patterns are global and not local as they are determined by relevant policies of industrialized countries while international demand is expected to continue to expand. Bioenergy accounted for 70% of renewable energy used in the world in the year 2019 of which 25% was used in transport sector mainly in the form of liquid biofuel [6]. However, the supply side especially in Africa represents a huge bottleneck that will reduce the expected potential return and income.

Eastern Africa countries are likely to play more important role on biofuel markets in the coming years because the demand for transportation liquid fuels is expected to continue growing. Investments in biofuel production in Eastern Africa do not primarily target the domestic market but is driven by market trends in developed countries. Nonetheless the developing countries have responded by encouraging domestic biofuel use, in particular through increases in mandates. Although there are suitable environmental conditions available for bioenergy crop production, the economic viability will largely be influenced by government policies and farm management practices, and it is essential to note that the most decisive policies and markets for biofuel production are clearly not originating from Eastern Africa countries.

The objective of this review is to evaluate the potential market and policy measures supporting liquid biofuel production in five Eastern Africa countries including Ethiopia, Kenya, Sudan, Tanzania, and Uganda.

Methods of the review

Scientific articles and reports related to liquid biofuel market and policy were reviewed by retrieving from internet search engines and from local archives that include unpublished grey literatures of interview of government policy makers and biofuel producers. The search was based on words and phrases that combine "liquid biofuel market + Eastern Africa, Ethiopia, Kenya, Sudan, Tanzania, and Uganda" and "liquid biofuel policy + Eastern Africa, Ethiopia, Kenya, Sudan, Tanzania, and Uganda" for journal papers published between 2002 and 2023. Market related searches included purchase of planting material and selling products like bioethanol, biodiesel and by-products. Policy measures considered also included land acquisition for liquid biofuel production, planting bioenergy crops, liquid biofuel processing, trading, blending and consumption. The highest number of literatures about 24 were obtained in 2011–2015 and the lowest about 4 were obtained in 2002–2005 (Fig. 1).

Main text

The competitiveness of African biofuels in the international market

Global plans striving to avoid exceeding a 2 °C global temperature rise anticipate the need to invest US$500 billion annually in the renewable energy sector; between US$25 billion and $50 billion of the total investment in biofuels. It is also anticipated that the biofuel sector will have to deploy between US$5 billion and US$10 billion for new capacity per year between 2030 and 2050 [7, 8]. In this context, 'biofuel' refers to 'liquid biofuels'. The demand for liquid biofuels at the beginning of the 2020s was lower compared to preceding years because of low prices of fossil fuels. However, liquid biofuels have

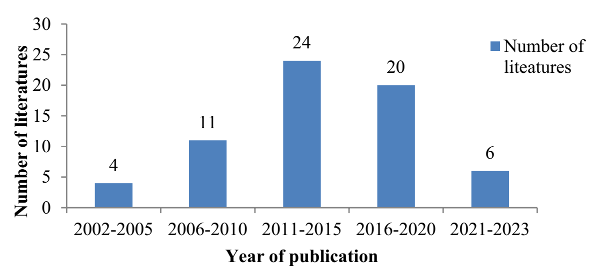

Fig. 1 Number of literatures reviewed with different year of publication

other benefits like producing by-products such as soap, or serving as cooking and lighting fuel in remote areas, where imported petroleum products are occasionally unavailable; biofuel also reduce smoke indoor pollution caused by solid biomass. Policies supporting liquid biofuels are highly important to tackle the fluctuating market prices of fossil fuels, the depletion of fossil fuel sources, thus securing supply to local energy needs, providing livelihood benefits and building capacity for future liquid biofuel production.

The global demand for liquid biofuel has been highly increasing since the 1980s. For example, although Ethiopia started bioethanol production in 1950s from sugar cane, the production was discouraged by then because of the lack of market demand. Biofuel demand in the transport sector, European Union (EU) renewable energy policies and favorable export market conditions [9] as well as attractive conditions as domestic cooking fuel in rural households push and support the demand for liquid biofuels, an aspect which is expected to persist due to climate change. This means that liquid biofuels are also highly needed in un electrified rural areas in addition to decarbonize the transport sector. In Eastern Africa, almost 80% of its population, more than 200 million people are without access to electricity [10]. For example, in Ethiopia only 14.25% of the total energy is derived from modern energy sources of electricity and fossil fuels and the remaining from solid biomass [10]. On the other hand great potential of liquid biofuels is available as evidenced from March 2011 to 2013 blending of gasoline and bioethanol as E10 (10% ethanol and 90% gasoline) in Addis Ababa fuel stations. About 38.54 million liters of ethanol was blended from 2009 to 2013, and saved US$30.2 million [11] from expending for fossil gasoline import. After 2017, the blending of ethanol for transport fuel was totally terminated because of shortage of ethanol by competing uses arisen for beverage industry. The production of biodiesel from the commonly known jatropha plant was negligible and terminated at trial stage [12]. The policies that assign ethanol for energy are needed instead of allocating for beverages at least by levying high tax on beverages.

In Kenya, bioethanol consumption was limited because of lack of awareness among users, 25% import tariffs, and 16% value added tax (VAT) treatment. If bioethanol would benefit from fiscal exemptions by the government, it could displace charcoal [13]. Studies such as Dalberg [13] recommended that the Kenyan government could consider providing incentives and subsidies either in the form of tax reduction for ethanol import, and/or production of ethanol within the country. In Kenya ethanol production from sugarcane and sweet sorghum was promising but did not contribute significant production. Communication with local people in Kenya in 2023 revealed that biofuel import tax was highly reduced. Farmers and research institutes had plantations for biodiesel production but not sustained and did not contribute for energy [12].

In Sudan, one sugar factory called Kennana produces 50% of the country's total ethanol in 2020. Earlier in 2009, Kennana sugar factory produced 65 million liters of ethanol and some 5 million liters of ethanol was exported to the European market. The total production was planned to grow to 200million liters in 2020 with annual production of 60 million liters bioethanol and 50 million liters biodiesel. There were a number of jatropha plantation sites but the production of biodiesel remained at trial stage [14, 15].

In Tanzania, the United Nations Industrial Development Organization (UNIDO) launched biomass pilot projects in villages in Kigoma and Dodoma regions to generate electricity from the palm oil seeds that had been growing since 1920 [16]. The Tanzanian Traditional Energy Development and Environment Organization (TaTEDO) installed oil seed extraction, grain dehulling/milling, and battery charging in Dares Salaam, Engaruka village located in Monduli district, and in Ngarinairobi village in the Arumeru district. The engines run on jatropha oil as well as on diesel during times of jatropha shortages. However, operating on diesel, the running costs were nearly twice that of the jatropha oil. The jatropha oil driven engines enabled to construct a village mini-grid that connects rural households and shops to supply light and provided battery charging [16]. However, the scale of production is limited and the 2021 assessment showed that Tanzania still imports raw palm oil from Indonesia and Malaysia to meet their supply needs for local refineries and soap manufacturers [12, 17].

In Uganda, there was a plan to produce 720million liters of liquid biofuel per year in 2012 and 2017 [18]. There was scarcity of biofuel, despite the presence of a naturalized variety of oil palm that has been grown in the country since the year 1910. NEMA [18] identified that the lack of synergistic inter-sectoral policies supporting small-scale bio-fuel developments at the local level slowed down the progress of the biofuel programs and that resulted in total failure [12].

As ethanol prices increase, sugar factories in many places choose to process relatively more sugarcane into ethanol by lowering the output of sugar placed on the market. The rising energy prices provide incentives for the production of ethanol, inducing increased demand for food crops by ethanol distillers. The demand and supply of ethanol have been affected by the prevailing policy with the net effect dependent on the final adjustments between food-based feedstock and biofuel/oil prices.

Higher productivity of sugar cane could prove sufficient to supply both food and biofuel. FAO [19] identified that there was decline in international crude oil and ethanol prices in Brazil that contributed to reduce the upward pressure on world sugar prices.

The trade patterns of biomass feedstock of liquid biofuel were influenced by policy measures on energy and climate aiming at diversifying energy resources, and mitigating climate change by reducing greenhouse gas emissions. The European Union has been an important import region. From 2000 to 2017, liquid biofuel production has increased 10 times from 18 billion liters to 134 billion liters in the world. The trade of hydrogenated vegetable oil was 17.3 billion liters, biodiesel 33.9 billion liters and bioethanol 82.7 billion liters [20]. Bioethanol is the largest liquid biofuel used in the global transport sector. In Eastern Africa, the highest bioethanol production was obtained in Kenya, about 413ML and the lowest from Ethiopia, about 80 ML in 2016 (Fig. 2) [21]. Biodiesel is also quite significant in production and advanced biofuels are gaining prominence recently globally; however, there was no record of commercial scale biodiesel production in Eastern Africa.

Although the affordability and sustainable sourcing for supply are major concerns, biomass for liquid biofuel production is expected to be a forcible important resource to mitigate climate change [22] because biomass is a resource for energy, material and chemical production. However, the supply and demand of biomass are not in balance, and more efforts are needed to adjust this situation. Since biomass is scarce and valuable, it cannot viably be used, at scale, in all the applications. For example in Europe, continuing the trends of a 150% increase in bioenergy since 2000 will hit limitations, and use 40–100% more biomass than what is likely to be available [23].

In the year 2030, the Eastern Africa mismatch between biomass supply and demand is expected to be about 119 and 129.48 Mtoe, respectively (Fig. 3) [24].

Eastern Africa liquid biofuel has a number of market opportunities [25], including domestic usage to replace increasingly costly fossil fuel imports, and export to the European market, either under the tariff-free privileges of the Everything-but-Arms initiative (EBA) or under the East African Community (EAC) interim Economic Partnership Agreement. Moreover, mandatory targets to replace fossil-based transport fuels in Europe and the US have generated lucrative demand. This indicates the remarkable potential market opportunities of liquid biofuel production for Eastern Africa, which motivates large-scale investors and smallholder farmers alike.

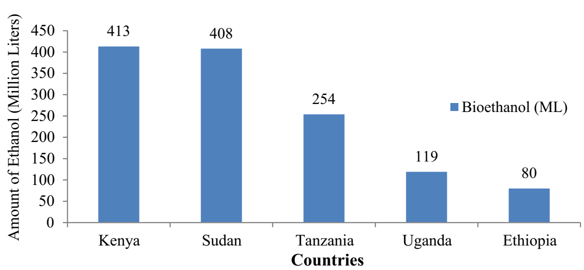

Fig. 2 Ethanol production in Eastern Africa in 2016 [21]

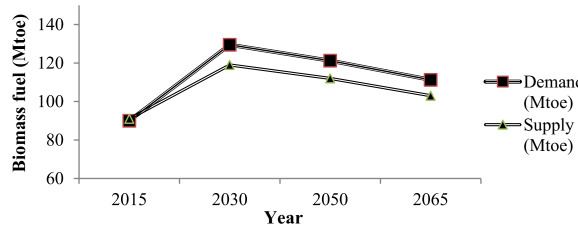

Fig. 3 The demand and supply of biomass fuel in Eastern Africa from 2015–2065

Purchasing planting materials

The bioenergy crops planting materials in the form of seedlings or cuttings need to be of high genetic quality, using locally adapted or adaptable varieties, providing high yielding, short growing time, and free from diseases and pests. In Eastern Africa different varieties of bioenergy crops are available but they are located in limited places. The purchasing of high quality varieties of planting materials is not common because of cost and the low attention given to the energy crops [12].

Purchasing and producing processing chemical inputs

The chemical inputs to the biofuel conversion processes, such as yeast for fermentation and methanol or ethanol and sodium or potassium hydroxide for transesterification, need to be produced locally and should be made available to the local bioenergy crop producers. In the process it is also important to replace petroleum products like hexane in oil extraction with organic materials like enzymes and local fungi. However, Eastern Africa countries were not well equipped with laboratory facilities of biofuel production. Most of the biofuel processing materials were short time donor project driven, and the once established laboratories are abandoned soon after the end of a project [12]. Therefore, biofuel processing activities should be incorporated in the usual research and development activities a country.

Selling bioethanol, biodiesel and by-products

The selling of bioethanol, biodiesel and by-products, such as bagasse and glycerol, need to start at the local market. Exceeding amounts after local consumption could be exported. Eastern Africa countries had been selling ethanol within the country or to neighbouring or foreign countries. However, the bioethanol market was not sustained because of the high rate of local consumption for non-energy uses such as beverage and feed. Selling of the seeds of jatropha biodiesel crop was started in Tanzania, Ethiopia and Kenya but discontinued because of the lack of large-scale supply, lack of continued attention by the government and low price of alternative fossil fuel in 2016–2021.

Evaluation of liquid biofuel markets in Eastern Africa

The biofuel markets had high demand side but the lack of sufficient supply and increased price of ethanol resulted in the failure of market of ethanol for energy. The price of imported fossil gasoline was by far lower than the locally produced ethanol in 2020. Moreover, sugar factories that produce ethanol are meant for profit making and the factories want to sell ethanol to purposes such as beverage industries at higher prices than to energy sector that want ethanol at lower prices. Then ethanol becomes unaffordable to the energy sector. The biodiesel market was not established because it was terminated at the trail laboratory scale because of the lack of finance for large-scale development [12].

Policy, and institutional frameworks for sustainable production of liquid biofuels

Liquid biofuel policies for climate change mitigation, energy security, including volatile oil prices and depletion of petroleum reserves in a growing number of industrialized countries have stimulated global interest in bioenergy crop production.

The bio-economy readiness index of African countries for climate action show that Kenya, Tanzania, Uganda, and Ethiopia ranked 2nd, 11th, 15th and 18th, respectively in the world. The development of liquid biofuel strategies and policy measures at national level is part of these countries' determination to implement bio-economy relying on an increased role of biofuels in the economy [26].

Liquid biofuel production is an inter-sectoral industry, and its economic viability depends on the policies of different sectors. Biofuel policy is in fact derived from the combination of different policies, which have different sets of objectives as defined in Global Bioenergy Partnership (GBEP), International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB) for liquid biofuels [27]. In the energy value chain, an organization developing liquid biofuels needs to collaborate not only with relevant industry sectors but also with other relevant institutions in research and development, seed certification and product quality assurance and marketing, including biofuel strategies formulated to optimize land use and to harmonize the existing land use policy with the energy policy [28]. Therefore, the bioenergy policy needs to be an integrated policy framework including energy, infrastructure, agriculture, forestry, other environmental resources and food, technological developments as well as research and innovation policies.

In Eastern Africa region, despite attractive legal conditions and political willingness to invest in liquid biofuel production, the institutions in charge of deploying relevant measures proved to be weak or their action turned out to be negligible. Then the Eastern Africa biofuel strategies just observed from 2007 to 2021 were weak and not updated to the prevailing conditions of local demand, and societal preference. Therefore new policies are highly required based on the needs of multiple stakeholders for the value chain of biofuel production and consumption. Although there was no country in the Eastern African region that developed a biofuel production and consumption policy, except Kenyan biodiesel strategy, biofuel crops were planted in many of the countries in the region. Therefore, appropriate policy based on the sustainability indicator criteria of GBEP, ISCC and RSB on liquid biofuel addressing the main challenges including achieving food security and energy security are still highly needed [27]. Some of the policy approaches required in Eastern Africa countries for liquid biofuel production are described in the following sections:

Land use, land acquisition, and land administration policies

The original land-use type of an area is diverse which include forest (woodland) or agriculture. Conversion of the land uses to biofuel crop land has long lasting negative consequence to the survival of humans and sustainability of the production. For example, the destruction of forests and important ecosystems like wetlands for biofuel investment may devoid other ecosystem services that lead to wild animals migration, and aquatic life destruction. National governments of Ethiopia, Kenya, Sudan, Tanzania and Uganda allocated large areas of land for biofuel production, but modern productive agricultural techniques are still in early stage. As a result the fertile forest lands are cleared for biofuel cultivation. Moreover, there is no national land-use policy in Ethiopia and Sudan [29–31]. Therefore, land-use zoning that restricts biofuels to areas not considered critical for other uses, such as conservation and food production areas should be practiced.

To facilitate biofuel investment, investor support services of acquiring land, establishment, and management are highly important. Appropriate compensation and establishment are required before displacement of people from their lands. According to Wiggins [25], 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 countries require national regulatory liquid biofuel framework, so that the land allocation is not driven by foreign investors and the local poor people and subsistence farmers are not driven off from their land. For example, the Tanzania liquid biofuel guideline [32] proposed to ensure no forced displacement of people for biofuels development. Therefore, in acquisition of land from local administration, proper discussion, agreement and compensation are required before implementation of investment.

It is also important to improve land productivity with natural soils fertility enhancers like compost, crop residue, manure, and litter. The destruction of forest and removal of solid biomass that degrade land fertility can be reduced by using alternative renewable energy sources, such as liquid biofuel, hydroelectricity, geothermal, solar and other energy sources [33].

Bioenergy crop production

The type of bioenergy crops need to be adaptable to soil and environment and suitable to local socio-economic condition. Non-edible bioenergy crops that do not compete with the food crop market are preferable. Moreover, perennials are preferred to annuals for liquid biofuel production by reducing annual management costs and by producing better viscous liquid biofuel. The jatropha oil as a perennial plant is a potential fuel because of its lower viscosity of 34–36 cST as compared to other plant oils like cottonseed (36 cST) and sunflower (43 cST) [34, 35].

Other studies also indicated that, the interest in local bioenergy production in some African countries, such as Tanzania, Kenya, and Uganda have been influenced by the discoveries of gas and oil reserves [36], which may reduce the interest for liquid biofuel. The European market and emission reductions for climate change would still continue to drive the viability of investments in liquid biofuel production. Moreover, the reduction of dependence on solid biomass would leave more biomass for liquid biofuel production for use in transport sector. Some of the renewable energy sources like hydro and wind power are more vulnerable to climate change shock. Therefore, sustainable supply of liquid fuel is highly important, as deep rooted higher plants are more resilient and tolerant to extreme levels of heat wave and drought than open placed water bodies. The deep rooted plants use the soil water till the return of another moist season as observed in many seasonal water storages and streams.

In most of Eastern Africa countries, the leaves of sugarcane are removed by burning. Therefore, policies are required to prohibit the burning of sugarcane fields and to use the biomass residues for energy purposes and/or to maintain the fertility of soil, since many of the Eastern Africa countries were biomass dependent. Moreover, technologies developed in Brazil should be applied to extract ethanol from sugarcane leaves in addition to cane juice [37].

In the Brazilian State of São Paulo (the Amazon Forest), where 60% of the nation's ethanol was produced, the deforestation rate was reduced in times of biofuel ethanol production from sugar cane cultivated over pasture and crop lands [38]. Despite less pasture area, the production of beef and milk in the state was substantially increased in the same period due to livestock intensification, yield growth and adoption of innovative agricultural management practices. Therefore, the use of land can be protected and enhanced when using appropriate management practices aimed at increasing productivity of energy and agricultural food crops and livestocks.

Biofuel processing and local people

Biofuel processing is the conversion of biomass feedstock to liquid biofuel. In Ethiopia, the export of feedstock to be processed to liquid biofuel had created a certain degree of conflict between investors and local people. Therefore, local processing was recommended. In Tanzania, there was an encouragement of local people involvement in the processing and value addition, in such a way that the processing of the final liquid biofuel needed to be within short distance from the cultivation area or country where the feedstock was produced. The Renewable Energy Policy for Uganda in 2007 planned to promote plantations of crops such as oil palm to fulfill blending mandates of at least B20 and E20 in the fuel mix and to provide financial incentives for the production of liquid biofuels by local farmers, while standardizing and certifying liquid biofuel [32].

Institutional coordination for liquid biofuel production

African biofuel coordination started in the first high level African biofuel seminar held at the African Union (AU) headquarters, in July and August 2007 in collaboration with Brazil. The seminar aimed at briefing potentials, risks and trade-offs about liquid biofuel to policy makers, private sector and regional institutions. The seminar declared sustainable biofuels development in Africa [39]. Moreover, it proposed government support and international collaboration on various aspects on the ways of making future liquid biofuel production sustainable in Eastern Africa. Later the different efforts dealt about individual countries. Then, there was no recorded collaboration and most of the strategies and ground performance of biofuel activities failed altogether as studied in 2021 [12], although there was a number of investors requested and acquired land for biofuel development.

In Ethiopia, the land allocation was by the Federal Government, Regional Governments, Ministry of Agriculture and Ministry of Investment that complicated monitoring of biofuel investment (it was difficult to know what hectarage of land was planted with biofuel crop or other agricultural crops, how much is the productivity per unit area and what inputs are required); and loosened the coordination (central government controls the land requested centrally and the regional do the same under the region, however, the use of different institution resulted in the same piece of land planned to be offered to different investors and different management plans proposed for the same piece of land) because of lack of strong institution on biofuel [40]. Therefore, a strong biofuel institution should be formulated by consensus of regional and central government based on agro-ecologies and land suitability of biofuel crops using similar rules and regulations. The land leasing period in Ethiopia in biofuel activity was not clear. However, at the stage of better coordination in Tanzania [32] land tenure of 25 years or less land lease period formulated depending on the crop characteristics.

In Tanzania, a decade or less of biofuel investment experience in the country showed 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. Sustainability of rural liquid biofuel projects require` gender based community participation in planning process, provision of seeds and other required inputs and effective use of new income generating opportunities [41]. However, the biomass and biofuel sector was suffering from the lack of a national policy framework for biomass energy; poor public awareness of biomass energy; complicated, often contradictory and poorly regulated governance of commercial biomass energy production and trade [42]. For example, the districts in Tanzania had executive officers, civil servants including agricultural officer, forest officer, health officer etc.; however, the energy sector has no district level direct executive officers responsible for energy matters. The issues of energy matters were handled by different departments, such as environment, forestry, health, and works, among others. Then energy issues are not considered at the district level where the resources are supposed to be managed [42]. Similar problems prevail in Ethiopia, Kenya, Sudan, and Uganda. Tanzania prepared liquid biofuel guideline in 2009 before formulating biofuel policy to fulfill the urgent need of clear guidance for the developing biofuel industry. The guidelines include institutional framework, application procedures for investors, and land acquisition and use from group of professionals from different sectors**.** Tanzania promoted liquid biofuel investment by establishing Tanzania Investment Center (TIC) where all applications regarding biofuel investments and development are submitted to the Biofuels One Stop Centre [43]. However, in 2016 the TIC activities were totally vanished without any recorded memory [12]. Therefore, good governance is highly important for bioenergy crop production, liquid biofuel processing and consumption in the whole value chain. Moreover, it is important to exchange good practices through cooperation, including—but not limited to—intra-African countries, which would accelerate the learning process and deployment of effective measures and mechanisms.

In Sudan the liquid biofuel institutions in 2015 respected the biofuel policies guidelines outlined in other Eastern Africa countries by recommending the formulation of common polices by neighboring countries on pricing and blending to prevent cross border smuggling [44]. However, Eastern Africa countries had no commonly agreed policies on liquid biofuel and further agreement is highly important.

Analysis made in NEMA [18] identified that in Uganda there was lack of synergistic inter-sectoral and appropriate policies that support small-scale bio-fuel development at the local level, which supposed to slow down the progress of the bio-fuel programs. Similar policy deficits were prevailed in other Eastern African countries. Therefore, inclusive liquid biofuel policy that spans across sectors instead of being traditionally handled separately, is highly important to motivate the liquid production at small and large scales.

Model and scale of liquid biofuel production

Models of liquid biofuel production can be (i) small scale and small holder private farms for domestic processing and use or for feedstock sell; (ii) out growers scheme to supply to large-scale liquid biofuel processors; and (iii) cooperative cultivators of bioenergy crops or large-scale bioenergy crop cultivators in plantations for large-scale processing. UN [44] proposed 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). There was lack of focus on smallholder farmers to produce bioenergy crops. The investment was based on large-scale plantation by displacing forest or other vulnerable ecosystems. However, smallholders are many in number and can bring change if they produce liquid biofuel and large investors are rarely obtained to produce liquid biofuel. In Tanzania, there was an encouragement of out-growers model or hybrid model (plantation and out-growers schemes), form associations/cooperatives of out growers [32]. Sulle, and Nelson [17] in Tanzania revealed that, biofuel companies using out grower and other contracted smallholder arrangements have little direct negative impacts on land access, which showed a positive model for local livelihoods and the environment.

Local development and job creation role of liquid biofuel

Small scale liquid biofuel productions are highly important because of the smallholder agrarian nature of the rural people of Ethiopia [29]. In the same token, the Eastern Africa countries have similar farming practice that requires the introduction of liquid biofuel crop production at the smallholder scale.

Africa had high rates of rural poverty, with over 80% of the rural population living under $2 per day [45], and bioenergy production was thought as one solution to reduce poverty and then liquid biofuel production need to be included with local development agenda of rural farming systems. Production and utilization of liquid biofuel in Africa could enable to strengthen management and use of forest ecosystems for sustainable development, address poverty eradication and environmental protection. Although progress is made in Sub-Saharan Africa in powering the region, efforts are still not keeping good pace with population growth. If there is no alternative energy sources such as liquid biofuel, deforestation will be unavoidable in Africa where, over 550 million people are without access to electricity and urged to solid biomass or firewood [46].

World Bank estimated that Sub-Saharan Africa could yield between 700,000 and 1.1 million jobs by a region-wide blend of 10% ethanol with gasoline (E10) and 5% biodiesel with diesel (B5). A study conducted in Southern Ethiopia showed that biofuel investments can have a "win–win" outcome that can improve smallholder productivity, and food security [40].

In China, production of crops to produce liquid biofuels is under the control of state- owned enterprises, and starting the production of biofuels from non-grain feedstock such as sugarcane, switch grass grown on degraded/abandoned land that facilitated the investment in liquid biofuels [47].

Market incentive based liquid biofuel policy instrument

The Ethiopian liquid biofuel sector was less competitive in 2016–2021 in comparison to fossil fuel and hydroelectric energy due to the lack of subsidy of technology incentives, efficiency and innovation [48]. Sudan proposed strategic commitment and formulated clear government policy regulations guidelines and incentives on liquid biofuel for transportation [49]. The main policy tools in the other Eastern Africa liquid biofuel production could be regulatory that embrace an array of state legislation comprising different sector policies and market based instrument including certified products of the envisaged market based on Chamdimba [50]. Moreover, it is necessary to include enforced blending mandate/targets to petroleum companies in national market, development of free trade zones that encourages exports, high importation tax on imported fossil fuels and limit imports, direct financial assistance in setting up biofuel projects, low interest, and co-investments, and tax rebates. The lack of enforced blending, some fuel companies or car owners were not interested to use the blended gasoline especially outside the capital city in Ethiopia in 2010–2017. The high level of import tax of liquid biofuel in Kenya reduced the interest to use imported bioethanol in 2016 that urged to use the local people to use either the cheap kerosene or firewood.

Market disincentive based liquid biofuel policy instrument

The production of bioenergy crops and processing to liquid biofuels can be increased by restricting some regulatory measures. For example, regulations on banning the use of food crops as biofuel feed stocks can reduce conflict with food production and encourage searching dedicated nonfood bioenergy crops. It is also important to restrict international capital flows through the arrangement of bioenergy crop cultivation, feedstock production and conversion to liquid biofuel in the same place to motivate local processing and to reduce the transport cost of bulky volume of unprocessed biomass. Similarly, adoption of production standards and certification of products increase the quality of liquid biofuel that attract better market. Moreover, business linkage between large enterprises, such as multinationals, and local suppliers can be designed in such a way that they facilitate technology/know-how transfer to the host economies in the value chain facilitates the quality and identify bottlenecks in a way of production and consumption of liquid biofuel. Export tariffs on feedstock that tax feedstock export more heavily than liquid biofuel will stimulate local processing [50].

Local utilization of liquid biofuel through innovation and efficiency

Ethiopian energy policy [29] proposes regulating switch to alternative fuels like liquid bio-fuels for medium and large-scale service establishments. It is important to increase energy security through promotion of liquid bio-fuels and other sources to run agricultural machinery and for power generation. The same plan was proposed in Kenya, Sudan, Tanzania, and Uganda.

It is widely recognized that the Eastern Africa region has rural areas which are not fully electrified from central grid system. Even the urban centers have shortage of electric power. Improved cook stoves of either biodiesel or bioethanol are required to supply alternative energy. For example, jatropha oil/ biodiesel cook stoves use pure or blended biofuels. Cook stoves imported from Germany had been used in Arusha, Tanzania since 2006 using oil from a local jatropha plantation [51]. However, the cost of importing the technology was unaffordable, while relying on local innovation could reduce the cost. Bioethanol cookstoves were traditionally used in Zimbabwe since long time, called gelfuel which had been used by soldiers or for recreational and catering applications. The ethanol stove also protected from indoor air pollution and associated problems. Another bioethanol stove was in use in Ethiopia in support of Gaia association [52].

South Africa also has practiced to scale up in producing and using biojet fuel from the energy-rich oilseeds of Solaris, a nicotine-free variety of tobacco. A certified 30% biojet from Solaris was blended with aviation fuel, and considered as the first to be used in African passenger flights made from Johannesburg to Cape Town on Boeing 737–800 s in 2016 [53].

Liquid biofuel research

In Ethiopia, there was insufficient research and development, and few number of human skill development on liquid biofuels [48]. There are some research activities on bioenergy crops and their processing in Kenya. Therefore, it is important to strengthen indirect assistance of liquid biofuel promotion through maintaining the agricultural extension services, that disseminate research results, scale out best varieties of bioenergy crops and popularize to train farmers. As a new investment venture, biofuel research activities are given less attention and results remain in the research plots and in scientific reports which are not accessed by farmers when compared with agricultural food or cash crops because of lack of fund for biofuel capacity building.

In China, support for research and development has encouraged liquid biofuel production [47].

Local liquid biofuel technology development and research was at infant stage in Eastern Africa which can be revealed by the absence of small scale development. Actually, no one can be blamed for the failure of lack of small scale biofuel development because the approach of liquid biofuel development was in top down fashion, where global climate change agenda of countries coupled with the lack of alternative energy sources for reduced emission initiated the liquid biofuel. Different biofuel literatures showed the lack of national/ regional research centers that include smallholder liquid biofuel production [17].

Many of the African countries had developed biofuel strategies and policy guidelines (without policy) that envision a contribution of biofuels to the national energy mix [54] to substitute the petroleum imports and to contribute to rural development [55]. Over 94 projects and 119,000 hectare were allocated to jatropha (*Jatropha curcas)* biodiesel in 2008 in Africa. However, the strategy was not implemented and the plan was failed, then a new strategy and policy is a future requirement. Only small proportion of the allocated land was planted to jatropha and some projects were failed to produce extensive oil, and only a laboratory scale small amount of oil and biodiesel was produced [56].

A number of previous studies revealed the large potential of Africa for growing liquid biofuel crops like jatropha in semi-arid regions [57]. Moreover, there was some previous knowledge in liquid biofuel in Africa. Uganda introduced oil palm in 1910. Tanzania has been cultivating oil palm since 1920s. Ethiopia started producing bioethanol from sugar cane molasses in 1950s. The South African Coal, Oil and Gas Corporation Limited (SASOL) gasification plant converted coal to diesel fuel, gasoline, chemicals and other products and converted synthetic gas (syngas) to liquid fuels in 1950, as a major foundation for development of technologies for liquid biofuel production from lignocellulosic feedstocks [58]. Some modification is required for the production of liquid and syngas from lignocellulosic feedstocks because such feedstocks have a higher oxygen content, lower energy density and different impurities than fossil fuels. Therefore, there are suitable conditions to promote liquid biofuel production in Eastern Africa and research based evidences should be at the top of the future policy agenda.

Advanced liquid biofuel

Biomass Energy Strategy (BEST) of Ethiopia, Tanzania and Uganda were prepared in around 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, second generation lignocellulosic ethanol and pyrolysis bio-oil production.

Training and capacity building

Africa had very limited experience of producing liquid biofuels [59]. It was hardly possible for local people, business doers or farmers that use traditional solid biofuel, firewood, to jump to liquid biofuel without training and availability of inputs, that include chemicals for the production of biodiesel (basic hydro oxides, and lower

Table 1 Domestic supply of biomass and liquid biofuel supply in continents in 2017. Source: [20]

Continent	Biomass (EJ)	Liquid biofuels (EJ)
Africa	15.4	0.00
Americas	10.8	2.57
Asia	21.6	0.35
Europe	7.52	0.73
Oceania	0.28	0.00
World	55.6	3.65

alcohols), and bioethanol (yeast or enzymes). At the global level, the total contribution of biofuels from Africa was insignificant [60], despite the continent's vast areas of land that are climatically suitable for biofuel feedstock production [61]. As shown in Table 1, the biomass production in 2017 was 15.4 EJ but the liquid biofuel was almost nil which indicated the lack of conversion skill, that enable the ability to convert oils to biodiesel and sugar to ethanol and technology and the liquid biofuel activities were totally terminated.

Liquid biofuel blending and consumption

Brazil was the second largest producer of biodiesel in the world in 2013 because of the government policy of a mandate that sales of diesel should include 5% biodiesel [62]. Successful countries in the production of liquid biofuel like China and Brazil used policy of long-term targets and planning, supported by government-controlled, subsidized prices, preferential taxes, low-interest loans, mandatory blending consumption of liquid biofuels [47]. Practically, subsidized prices result in uncompetitive and ineffective value chains, then detail training of the activities of blending and consumption of the blend that strengthen shareholders is preferable.

Financing liquid biofuel investment

Integration of local finance and microfinance institutions that understand local markets, conditions, clients and additionally engaging international institutions, like multilateral and bilateral donors for sustainability of liquid biofuels is important. The carbon financing of small-scale liquid biofuels projects need to be explored in Eastern Africa, as energy mix as proposed in Conference of Parties (CoP) 27 (CoP27, 2022) [63].

Lessons to African countries

Studies showed that Brazil, India and Malaysia are liquid biofuels exporters. Similarly, African countries like Ethiopia, Kenya, Uganda, Madagascar, and the United Republic of Tanzania and many others are with similar climate and available land which could be important liquid biofuel exporters [64].

After 2007, Eastern African countries like Sudan progressed well in liquid biofuel production with one of its sugar company called Kenana that exported some 5 million liters of ethanol to the European Union in 2009 and planned to produce 200milllion liters of ethanol per year in 2020 [14].

In 2016, Swaziland produced about 480ML of bioethanol and Ghana produced 50ML of biodiesel from sugar cane molasses and jatropha oil, respectively to the world market. Sugar cane molasses is a popular feedstock for bioethanol production in many African countries, while jatropha oil seeds are common for biodiesel production. In Fig. 4, bioethanol in all countries is from sugarcane molasses except Benin that produce from cassava and Guinea from Cashew. Biodiesel in all countries shown in Fig. 4 was produced from jatropha [21]. The east African countries had reported no biodiesel. Therefore, Eastern Africa countries should share experience from other countries within and outside Africa.

Evaluation of Eastern Africa biofuels policies, strategies and plans

The biofuel policy guidelines, strategies and plans are theoretically well prepared in Eastern Africa Countries. However, the practical implementations of the policies were very low. The lack of experience in the production of liquid biofuel in smallholder farmers, and large-scale investors, the competition for land with food crop or grazing or forest land, poor productivity of biofuel crops, competition of interest in the use of sugarcane ethanol from sugar factories, lack of incentives in the value chains for blending, and lack of finance for research and development resulted in failure of the biofuel policy guidelines, strategies and plans. The biodiesel production activities were terminated and all investors for the

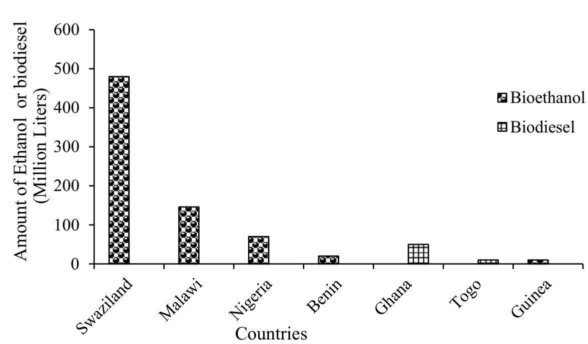

Fig. 4 Bioethanol and biodiesel production in some African countries (Source: [21])

same reason abandoned the business. The ethanol activity mostly related to the government sugar factories was over taken by the beverage industry, use of molasses for livestock use and other related purposes. Therefore, a biofuel policy that aims at the use of liquid biofuel for energy including household energy, transport and small agricultural machinery are highly needed [12].

Conclusions and recommendations

Sustainable liquid biofuel production requires good governance, well-coordinated, financed and stable institutions; market based voluntary certification, and appropriate management strategies. Moreover, conserving biodiversity, crop and soil productivity are essential for sustainable biofuel production. Commercially available liquid biofuels provide integrated income for rural communities like energy, material and chemicals together with climate change mitigation options. Production of advanced liquid biofuel from lignocellulosic feedstocks was limited by low technological development in Eastern Africa. Liquid biofuel production has a complex relationship and challenge with food crop production as they are produced by using the same piece of land and water resources. Therefore, a combination of government support, private sector entrepreneurship and Non-Governmental Organization outreach are required for the successful production of feedstock for liquid biofuel.

Unsustainable biofuel crop production was blamed for various environmental problems. The African Biodiversity Network recommended that the biofuel development in Eastern Africa, Tanzania, Kenya and Ethiopia to be only small-scale rural-based investments that benefit local communities without adversely affecting biodiversity, food production, and land rights. Moreover, large-scale mechanized biofuel investments are needed in areas where there is no land use conflict among forestry, agriculture and grazing land to generate government revenue because smallholder traditional cultivations may not be sufficient to accomplish tasks in short period of time. The inclusion of a pre-investment practice of environmental and social impact assessments need to be part of the African liquid biofuel development policy. Many other studies also stated the need for well-researched sustainability standard certification and GHG emission guarantees of biofuels production based on International Sustainability and Carbon Certification and Roundtable on Sustainable Biomaterials. The review of many other biofuel researches revealed that improving biofuel productivity [27] with social, economic and environmental viability without compromising food and land is important to determine the appropriate scale of liquid biofuel production.

The Eastern Africa countries have different types of renewable energy sources other than liquid biofuels, which lessen the desire and promotion of liquid biofuel. However, a Duty-Free Access to the EU market for Ethiopia, Sudan, Tanzania, and Uganda, and the need for foreign investment currency, and being additional income source for rural mechanization should motivate to produce liquid biofuel. Moreover, the renewable energy sources like solar, wind, biomass and hydroelectric power are vulnerable to climate change impact and therefore, liquid biofuel with its long time storable facilities are important energy sources. Moreover, deep rooted, drought tolerant, biofuel producing plants can absorb water from deep soil sources in times when the surface water is evaporated. The development of liquid biofuels industry in Eastern Africa need to select high yielding varieties of perennial crops over annual energy crops, use multipurpose crop diversification, use inter- and multi-cropping agroforestry practices, and improve energy efficiency. In Eastern Africa, most of the large-scale liquid biofuel investors were foreign companies and the local ones were few. Therefore, it is important to raise the awareness level of the local investors, targeting primarily farmers and traders to inform about the significant, alternative benefits and opportunities of liquid biofuel. Many of the studies and assessment of literature in Eastern Africa liquid biofuel development revealed that the sector is in early establishment stage. Policy and guideline formulation and infrastructure development were in operational phases. Therefore, to recommend potential policy options that remove barriers and enhance benefits of sustainable biofuel development, there should be further research in the region about the whole life cycle in the value chain of liquid biofuel production, processing and consumption by establishing good governance and sharing experience.

Abbreviations

AU	African Union
B20	20% Biodiesel and 80% diesel used in blending
BEST	Biomass Energy Strategy
E10	10% Ethanol and 90% gasoline used in blending
EAC	East African Community
EBA	Everything-but-Arms initiative
EU	European Union
GBEP	Global Bioenergy Partnership
IISD	International Institute for Sustainable Development
Mtoe	Metric tons of oil equivalent
NGO	Non-Governmental Organization
SASOL	South African Coal, Oil and Gas Corporation Limited
TaTEDO	Tanzanian Traditional Energy Development and Environment Organization
TIC	Tanzania Investment Center
UN	United Nations
UNIDO	United Nations Industrial Development Organization
US$	United States of America Dollar currency
VAT	Value added tax

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