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# Potential for production and use of liquid biofuels as a strategy for developing green and circular economies in Southern Africa

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The Southern African Development Community (SADC) responded to global calls to address environmental challenges such as high greenhouse gas (GHG) emissions through the use of liquid biofuels. This study assessed the potential of liquid biofuel production in the SADC region with data collected in Malawi, Mozambique, South Africa and Zimbabwe. The results showed that the liquid biofuel industry is struggling. Countries do not have enough resources to support the industry effectively and there is overreliance on international sponsors. In terms of policy and regulatory frameworks most countries are doing well. However, these policies are not implemented effectively. Most countries use sugar-cane to produce bioethanol. Over the years countries, such as Malawi, have attempted to incorporate crops such as cassava (*Manihot esculenta*) and castor bean (*Ricinus communis*). Although the industry is not performing well it has contributed massively to livelihood development in all the region.

**Keywords:** feedstock, fossil fuels, GHG emission, liquid biofuel, SADC

## Introduction

Biofuels (liquid, solid and gas) are a source of renewable energy used in heating, cooling, electricity and transportation (Stafford et al. 2019). These biomass-derived fuels include wood pellets, biogas, ethanol and biodiesel. This study, however, focused on liquid biofuels. Most southern African countries depend on imports of petroleum products to meet energy requirements. Thus biofuels could improve energy access and security as an alternative to oil imports while providing opportunities for economic growth and rural development through the cultivation and production of feedstock (Stafford et al. 2019). Furthermore, biofuels provide opportunities for reducing greenhouse gas (GHG) emissions by between 30% and 50% compared to fossil fuels (Stafford et al. 2019; Ernst et al.). Globally, there is an anticipated increase in biofuel demand driven largely by country commitments under the climate change Paris Agreement of 2015, including the European Union (EU) and the United States of America (Stafford et al. 2019; Kargbo et al. 2021). Most countries in the global North will not be able to produce sufficient biofuel to meet their commitments which opens opportunities for SADC countries to produce bio-energy feedstock for both national and export markets (Stafford et al. 2019; Jain et al. 2022). Reports indicate that Democratic Republic of Congo (DRC), Angola, Mozambique, Tanzania and Zambia have allocated 10% of their cropland to

energy crops to cover their energy needs (von Maltitz and van der Merwe 2017; SARDC 2017a). Investment in liquid biofuel production requires balancing various land uses, including land allocations for energy feedstock and food production, and forest conservation (Stafford et al. 2019; Kargbo et al. 2021). For the SADC countries food security is a top priority given the growing population which may affect the availability of land for feedstock production.

The literature shows that land use conversion in Africa and in SADC continues to increase through agricultural expansion, uncontrolled fires, industries and settlement and the related GHG emissions match emissions from the use of fossil fuels (Kargbo et al. 2021; Ernst et al. 2024). Thus the development of liquid biofuel could drive further land use conversions. This therefore requires targeted policy and strategic frameworks to guide responsible liquid biofuel investments. The use of fossil fuels has created environmental challenges worldwide, attracting international attention. The Paris Agreement requires all countries to reduce their emissions and at least reach net zero emissions by 2050 (Davis et al. 2018; IPCC 2021; Mostefaoui et al. 2024). The Regional Carbon Cycle Assessment and Processes (RECCAP) project estimated that Africa may have transitioned from a net sink to a net source of CO<sub>2</sub> in the last two decades (Ernst et al. 2024) while estimates based on United Nations Framework Convention

on Climate Change (UNFCCC) reports showed that GHG emissions range from 2.2 to 3.2 Pg CO<sub>2</sub>e yr<sup>-1</sup> between 2001 and 2017 (Davis et al. 2018; Mostefaoui et al. 2024). The International Council on Clean Transportation (ICCT 2018) reported that the SADC region, except for South Africa, contributes about 2.2% to global GHG emissions. Africa and SADC will have to reduce emissions and there are opportunities to achieve this through liquid biofuels, including helping other countries meet their emission reduction targets (Jones 2023; Yan et al. 2023). However, SADC countries have experimented with and used liquid biofuels for many decades, including in Zimbabwe (since the 1970s); Malawi (1980s); and South Africa (from the 1920s to the early 1960s), where bioethanol from sugar-cane has been used for petroleum fuel blending. Although this has happened at a limited scale and success in South Africa, it was stopped due to policy inconsistencies, food production concerns and high production costs (von Maltitz and Brent 2008; Pradhan and Mbohwa 2014). Current trends of liquid fuel production are, however, not fully understood.

Hence, the aim of this study was to assess the potential for producing and using liquid biofuel as a strategy for developing green and circular economies in SADC. The objectives of this study were to:

- a. assess trends on the status of liquid biofuel production; processing and consumption; land allocated for production of liquid biofuels; availability of feedstock for different liquid biofuel production from agricultural crops in specific areas in the selected countries; and GHG emissions associated with liquid biofuel production and use in southern African countries;
- b. evaluate opportunities, challenges and prospects in production and use of liquid biofuels as well as coping mechanisms for addressing the challenges;
- c. assess the effect of liquid biofuel production on cropland on forest margins and the implications for food security and primary forest cover loss (deforestation and forest degradation);
- d. assess the competitiveness of African biofuels in the international market; and
- e. identify policy regulatory and institutional frameworks relevant to sustainable production processing transport and consumption of liquid biofuels in the context of changing climate.

## Materials and methods

The study was conducted in four purposively selected SADC countries: South Africa, Mozambique, Zimbabwe and Malawi. These countries were selected owing to their involvement in liquid biofuel production, the potential for improving liquid biofuel production, and the availability of biofuel strategies or policies. The total land area and estimated populations in the four selected study countries are, respectively: 1 213 090 km<sup>2</sup> (South Africa, population 64 489 048 22); 94 280 km<sup>2</sup> (Malawi, population 22 017 855); 786 380 km<sup>2</sup> (Mozambique, population 35 277 238); and 386 850 km<sup>2</sup> (Zimbabwe, population 16 839 624). Most importantly, South Africa, Zimbabwe and Mozambique share borders and Malawi shares a border with Mozambique (Figure 1).

## Data collection and analysis

This study collected secondary and primary data using a semi-structured key informant-targeted questionnaire. As the significance of key informants is noted in the literature, the key informants in this study were chosen to provide in-depth outlooks and reasonable insights on specific questions (Pahwa et al. 2023) concerning biofuel production. Data sources included literature on liquid biofuels through published studies in peer-reviewed journals, country reports, policy briefs, technical papers with country case studies, and national policies and/or regulations on biofuels. These were reviewed to appreciate the history and determine the trends in biofuel production. This study sampled and/or targeted key informants, including government officials, farmers and company representatives in the biofuel production value chain. Most importantly, the questionnaire gathered information about biofuel production from the perspective of feedstock production, the size of the land available for planting the feedstock and the processing of the feedstock into liquid biofuel. Furthermore, the questionnaire focused on understanding the potential of improving the biofuel economy from the perspectives of policy and production. The questionnaire was administered by experts from the four SADC countries (South Africa, Zimbabwe, Malawi and Mozambique).

The South African interviews of the key informant were conducted with one government official from the Department of Agriculture Land Reform and Rural Development (DALRRD), and one official each from Biofuel Business Incubators (BBI), the Industrial Development Corporation (IDC), Coega Development Corporation (CDC), and a forestry company. Due to the Covid-19 pandemic lockdown regulations, the farmers' questionnaire was not administered. Nonetheless, the potential farmers earmarked to produce sugar beet for biofuel feedstock did not see a meaningful return on investment. In Zimbabwe, five government-targeted questionnaires were administered to two agricultural extension officers, one forestry extension officer, one official from the Ministry of Energy and Power Development (MoEPD) and one official from the Zimbabwe Energy Regulatory Authority (ZERA). Only two of the targeted government agencies responded to the questionnaire. All six targeted farmers (two each from the Chiredzi, Chisumbanje and Mudzi districts) responded to the farmer-targeted questionnaire.

In Malawi the interviews were conducted with officials from two companies involved in liquid biofuel production, Ethanol Company Limited (Ethco) and PressCane Limited, and with 40 sugar-cane farmers. Officials from the Department of Environmental Affairs and the Department of Energy were interviewed as well. Three data collection techniques were integrated to carry out this research: questionnaires, field visits and literature review. (Questionnaires were sent out to the respondents through emails and the WhatsApp platform. Additionally, physical and virtual meetings were scheduled with respondents where applicable. The farmers' questionnaires were however administered physically as the majority of farmers do not have smartphones.)

In Mozambique, the interviews and field visits took place in Maputo city and Maputo province. Interviews were conducted with various stakeholders from the government, private



**Figure 1:** Map depicting (a) location of the study countries in Africa, and (b) the four countries studied

sector companies, and farmers involved in the biofuel value chain. The government entities contacted during this study were Ministry of Land, Environment and Rural Development the (MITADER), the National Petroleum Institute (INP), the Ministry of Transport and Communications (MTC), National Directorate of Energy (DNE), National Directorate of Hydrocarbons (DNHC) and Fundo de Energia (FUNAE). Of these entities contacted only two (DNE and DNHC) were interviewed. Two private companies participated in the survey, Açucareira de Xinavane (Xinavane Sugar Factory) and the fuel acquisition and distribution company, PETROMOC. The data collected from the key informants were processed using content and thematic analysis. The country-specific data were transcribed and organised by each country expert in preparation for analysis where themes were identified.

## Results

### **Assessment of trends on the status of biofuel production at SADC level**

Some countries are at the preliminary stages of producing liquid biofuels while a few have been in business for some time and have experienced some success and failure. The major hindrance to production is the unavailability of resources to invest in technology and human resources to expand the sector. Bioethanol production seems more successful than biodiesel as it is difficult to produce biodiesel feedstock. Common liquid biofuel feedstock includes jatropha, sugar-cane, cassava, sweet sorghum, rapeseed, macadamia, palm oil, soya beans and sunflower. All four countries included in the study produce sugar-cane; some use it solely to produce sugar while others sell molasses to bioethanol-producing countries.

#### *Mozambique*

Liquid biofuel production in Mozambique started in 2003 and increased between 2008 and 2013 due to increased

liquid biofuel demand from foreign investors. By 2013 a total of 49 liquid biofuel projects had been established (40 being biodiesel projects). However, most projects, particularly those dependent on jatropha production, were unsuccessful. Consequently, liquid biofuel production stagnated in Mozambique with no concrete initiatives to revamp the sector. The country did, however, establish a biofuel policy that stipulates liquid biofuel blending mandates as follows: (a) B3 (pure gasoil–biodiesel blend containing 3% by volume biodiesel and 97% by volume diesel); and (b) E10 (anhydrous gasoline–ethanol blend containing 10% by volume of ethanol and 90% in gasoline volume) (Atanassov et al. 2017; Hartley et al. 2019). Notably, liquid biofuels have until now not been used for local consumption.

#### *Zimbabwe*

Sugar-cane and jatropha are the main liquid biofuel feedstock in Zimbabwe. Finealt Pvt Ltd (a government company) has been mandated to produce biodiesel from jatropha. The company has a landholding of 6 000 ha of which only 100 ha is being utilised; it has the potential to expand beyond 15 000 ha. Sugar-cane is produced in Chiredzi and Chisumbanje districts, with a combined cultivated area of about 63 000 ha. Chiredzi accounts for about 48 000 ha of the combined cultivation. Tongaat Hulett and Green Fuels are the major private companies supporting sugar-cane production. Green Fuels, which directly manages over 15 000 ha, primarily focuses on bioethanol production and Tongaat Hulett focuses predominantly on sugar production. However, given that ethanol is a by-product of sugar, the sugar-cane that passes through Tongaat Hulett also finds its way to bioethanol production. Tongaat Hulett directly manages 24 000 ha of sugar-cane plantations. The company is also the sole buyer of all the sugar-cane produced by 1 200 small-scale farmers.

#### *Malawi*

Kasinthula Cane Growers Association (KCGA), in Chikhwawa, and Dwanga Cane Growers Association (DCGA), in Nkhotakota, are the main sugar-cane producing associations in the country. KCGA and DCGA produce a combined total of over 190 000 tonnes. ETHCO and Press-Cane are private companies that produce bioethanol from molasses. These companies are supplied by the growers' associations and purchase about 46 000 tonnes of molasses from Salima Sugar Estate and associated Illovo companies, which are the largest producers of sugar in Malawi, and sell large quantities of molasses to biofuel companies. They also import molasses from Mozambique and Zambia. These companies produce an average of 15.5 million litres of liquid bioethanol annually. Like all the SADC countries, Malawi does not produce enough liquid biofuel to satisfy domestic demand. Currently liquid biofuels provide 4% of transport energy from locally produced bioethanol and biodiesel blended with petroleum fuels.

#### *South Africa*

South Africa has identified sugar beet, sweet sorghum, sugar-cane, maize, cassava, grain sorghum, soya bean and sunflower as ideal for liquid biofuel production. Maize has been banned as a biofuel feedstock due to food security concerns. The use of Cradock sugar beet to produce bioethanol has

been piloted. This pilot was initiated by the Central Energy Fund (CEF), a state-owned company, and the Industrial Development Corporation (IDC). However, it was later confirmed that commercial-scale biofuel manufacturing is not financially viable at the prevailing feedstock and conventional fuel prices. Crops such as ground nuts, soya bean and sunflower are also touted as potential feedstock crops for biodiesel. Even though soya bean (*Glycine max* L. Merr.) is a food crop, it was not banned for use as a feedstock because only 9% of soya bean grown is used directly for human consumption. For example, one tonne of crushed soya bean produces about 28% of oil and the rest is used for animal feed. South Africa is piloting a Biofuel Business Incubators (BBI) project which recycles cooking oil to produce biodiesel. The South African transport industry needs between 135 500 and 248 286 ha of land for biofuel production to satisfy its needs. The introduction of flexible-fuel cars could see this figure increase to about 440 000 ha.

## Discussion

### **Assessment of trends on land allocated and availability of feedstock for production of liquid biofuels**

More than 60% of the people in Mozambique and Zimbabwe reside in rural areas whereas more than 70% live in rural areas in countries such as Malawi (Sekoai and Yoro 2016; International Energy Agency 2017). SADC countries have been sceptical about the use of land for liquid biofuel production because of the direct competition with food production. Over 16 million ha of land in Mozambique is suitable for crop production (Hartley et al. 2018). Notably, this study revealed that the country has committed about 695 631 ha to biofuel production. Further, this research revealed that Kasinthula Cane Growers Association and the Dwanga Cane Growers Association are producing sugar-cane (as liquid biofuel feedstock) in Malawi with a combined area of 183 ha. The country has great potential for increasing production given the ample land and participation of farmer associations. In Zimbabwe three companies are producing sugar-cane on a combined area of 102 000 ha. Finealt Pvt (Ltd) has committed 6 000 ha for jatropha production. Smallholder farmers have contributed a total of 24 000 ha for sugar-cane production (biofuel feedstock). These farmers have personal land ranging from 2 to 5 ha which they commit to form the sugar-cane growers' associations. There is no record of land allocation for biofuel production in South Africa either than the 135 500–248 286 ha earmarked for soya bean production.

Sugar-cane is the main feedstock for bioethanol production in the SADC region. All the selected SADC countries are involved in the production of sugar-cane. However, not all the sugar-cane produced is dedicated to liquid biofuels, given that some countries focus mainly on sugar production and only use the by-product (molasses) for liquid biofuel. Jatropha has been identified as the region's major feedstock for biodiesel production (Redant et al. 2022), however, the production of this feedstock is minimal and most jatropha projects have not been successful. South Africa is the only country in the region that recycles cooking oil to produce biodiesel. The study revealed that Mozambique has invested over US\$1 bn in biofuel feedstock production, mostly jatropha. Nonetheless, the jatropha investments in Mozambique experienced low

yields (Slingerland and Schut 2014); this failure of jatropha investments led to a land use change in favour of other crops (Antwi-Bediako et al. 2019).

Sugar-cane produced in Malawi does not meet the demand of the liquid biofuel companies. The country therefore imports molasses from Mozambique and Zambia. The Malawian company that produced biodiesel shut down due to inconsistent feedstock supply (Government of Malawi 2018). Jatropha expansion initiatives have failed in Zimbabwe leaving idle a biofuel plant able to process 100 million litres per year. As such biodiesel produced from jatropha has remained minimal in the region. South Africa has listed jatropha as an alien invasive species, so does not promote production. Apart from South Africa, all the other SADC countries have great potential for producing jatropha feedstock but the agronomic requirements for this seem challenging for these countries. Other feedstock that could be used in the region is presented in Table 1 and includes edible sources such as sorghum and cassava (Stafford et al. 2019). The usage of biofuel feedstock that double as food crops is discouraged (Kunz et al. 2015).

### **Assessment of trends for liquid biofuel production from food crops in Southern Africa**

The study revealed that in the countries surveyed most of the land used for liquid biofuel feedstock, particularly sugar-cane, could be used for food crop production. As a feedstock, sugar-cane production competes with staple food production as it takes up large areas of land and a lot of water. Other potential feedstocks that compete directly with food security include cassava, sorghum, castor oil and maize (which is not used owing to this concern). Moreover, these crops currently produced as feedstock are grown at levels too low to merit any concern. Jatropha is produced in degraded areas unsuitable for crop production but could be used for livestock grazing and forestry. It can also be grown as a hedge/live fencing. Our research also revealed that liquid biofuel production supports the food and feed production system through, for instance, molasses by-products used as feed for livestock and filter cake applied to soil to improve soil fertility. Generally, however, liquid biofuel production competes with food and feed production. Only biodiesel production from jatropha does not directly compete with food or animal feed (Resch and Emme 2022).

### **Assessment of trends on production processing and consumption of biofuels**

SADC countries are slowly embracing the production and use of liquid biofuels as a partial substitute for fossil fuels in the transport sector. The study revealed that SADC countries use biofuel in three different ways: (a) blending with petrol/diesel; (b) industrial ethanol; and (c) sanitising. The governments have formulated policies guiding the processing of biofuel in the region. In Malawi all fuel companies blend ethanol with petrol at 20:80 (20% ethanol and 80% petrol). Mozambique has a B3 and E10 blending mandate while Zimbabwe has an E20 mandate (Alves 2014; Scoones et al. 2017; Government of Malawi 2018). South Africa has developed a biofuel policy (DMRE 2020) but it has yet to be implemented. The country has established E2 and B5 mandates for bioethanol and biodiesel respectively. Further, South Africa has established five major companies to create opportunities for economic

**Table 1:** Feedstock available for liquid biofuel production in Africa

Crop	Yield (l ha <sup>-1</sup> )	Countries that grow the feedstock
Palm oil	5 950	Angola, Ghana and Tanzania
Soya bean	446	DRC Malawi*, South Africa* and Tanzania
Coconut	2 689	Mozambique* and Tanzania
Jatropha	1 892	All SADC countries except South Africa
Sunflower	952	Angola, Malawi*, Botswana, DRC, Mozambique*, South Africa*, Namibia, Zimbabwe*, Zambia and Tanzania
Cotton seed	325	Angola, Malawi*, Mozambique*, Tanzania, Zimbabwe*, Zambia and South Africa*
Avocado	2 638	DRC, South Africa* and Tanzania
Groundnuts	1059	Malawi, Angola, Ghana, DRC, Mozambique*, Tanzania, Zimbabwe* and Zambia
Cashew nut	176	Angola, Mozambique* and Tanzania
Castor beans	1 413	Angola, DRC, Tanzania, South Africa* and Mozambique*

Source: adapted from Henley and Fundira 2019, and Kowalski et al. 2022; \* = country represented in this study

growth through liquid biofuel production. Towards achieving this, the assessment of the water requirements of grain sorghum, sugar-cane, sunflower, soybean and canola as feedstock for both bioethanol and biodiesel has shown positive results (Kunz et al. 2015).

Triangle/Hippo Valley and Green Fuel are Zimbabwe's biggest liquid biofuel production companies with a capacity of 40 and 120 million litres annual production respectively. Green Fuel is planning on up-scaling to about 450 million litres a year. In Malawi ETHCO and PressCane have production capacities of 18 and 14 million litres of bioethanol annually. Furthermore, these companies produce a combined total of about 31 million litres of bioethanol from feedstock imported from Mozambique and Zambia (17 and 14 million litres from ETCHO and PressCane respectively). Despite the high investment of over US\$1 billion in Mozambique, liquid biofuel production has stalled. However, the country continues to produce sugar-cane for the production of sugar and exports molasses to PressCane, a bioethanol producing company in Malawi. South Africa produces 155 million litres, and Zambia 137 million litres, annually.

#### **Assessment of trends on GHG emissions associated with biofuel production and use in selected countries**

One of the world's greatest challenges is the potential impact of climate change. In order to limit global warming to 2 °C (the level estimated as necessary to avert catastrophic climate change) the atmospheric concentration of GHG must not exceed 450 ppm CO<sub>2</sub>e5A (Verhe et al. 2020). Africa's emissions average between 1.3 and 1.5 billion tonnes of CO<sub>2</sub>e per annum and need to be further reduced (Davis et al. 2018). This study established that there are no significant attempts to quantify GHG emissions from the liquid biofuels sector probably because of limited technology, lack of expertise and insufficient financial resources. None of the surveyed countries have comprehensive data with regard to the amount of emissions, but there is evidence that the industry is contributing to GHG emissions. However, in South Africa the Department of Forestry Fisheries and Environment is currently and generally measuring the country's GHG emissions. Governments from the surveyed countries comprehend that establishing a biofuels production industry value chain would contribute significantly to reducing GHG emissions. The main pollutants include carbon monoxide,

methane and effluent from the processing plants, smoke from sugar-cane pre-harvest burning, and smoke from machinery usage. The sector is associated with emissions throughout the value chain.

Since most of the countries in the region produce liquid biofuels from sugar-cane the prospects of reducing GHG emissions are high. Rogowska (2017) and ICCT (2018) observed that ethanol produced from sugar-cane has the highest GHG savings of 70% to >100%. Maize is the second highest with emission savings of up to 60% but it has the potential to cause high emissions of over 5%. Biodiesel could save up to 20% but has the highest negative emissions of up to 50% (EPA 2018; REN21 2018). Biodiesel production is very low in the region because of the failure of jatropha projects. Most of the other biofuel feedstock are food crops (castor beans, soya beans, etc.) and cannot be produced in large quantities. Basically, use of biofuels has the potential to reduce GHG emissions to lower levels than those resulting from the use of fossil fuels.

#### **Evaluation of opportunities challenges and prospects in production and use of biofuels**

Liquid biofuels have socio-economic and environmental importance. The SADC region has great potential for liquid biofuel production. The region needs strategies and a plan of action to make this sector successful (Ganguly et al. 2021). Fuel is very expensive in the region given that the largest fossil fuel producers are not in the SADC region. The use of liquid biofuel could help countries save a considerable amount in finances and improve their gross domestic product (GDP). However, each SADC country should strive to eliminate the use of unblended fuel at the national level before aiming at exporting (Singh et al. 2019). Surprisingly, some countries like Mozambique have produced liquid biofuel but have never used it locally. The research revealed that some countries already benefit from the liquid biofuel sector even though production is currently below local potential. This sector has a positive impact on economic growth, environmental sustainability and employment creation, and has good prospects for future development (Hartley et al. 2018). However, there are challenges and the SADC region has the ability to overcome these challenges. Table 2 summarises the opportunities, prospects and challenges of the liquid biofuel industry as revealed by this research.

### *Opportunities*

The liquid biofuel sector has created jobs and allowed smallholder farmers to be entrepreneurs. This study revealed that Zimbabwe has created about 1 200 entrepreneurs who are contract growers for liquid biofuel companies. These entrepreneurs employ people throughout the production season. Mozambique has created over 14 000 jobs since the biofuel industry was established. Malawi has two of the biggest biofuel plants in the region and employs an undisclosed number of people. The findings of this research coincide with those of REN21 (2018) who reported that a larger portion of the 62 000 renewable energy jobs in Africa come from the SADC region.

Land in the rural areas is free for development and affordable for local people. Most of this land is inherited from ancestors. Smallholder farmers on this land form biofuel feedstock grower associations to leverage on volume and resources. Such associations get funding to invest in biofuel feedstock from the national government or international funding agents such as the United Nations and the EU. Production of feedstock for liquid biofuel has given farmers the opportunity to diversify and have an alternative cash income. Liquid biofuels have a stable market within the SADC region and abroad. The South African biofuel market can consume all the SADC liquid biofuel production given the demand of between 300 and 1 400 million a year (SARDC 2017a; Gasparatos 2018). These demand projections do not include the potential use of flexible-fuel cars in South Africa. A 40% flexible-fuel car penetration rate could increase the demand to around three billion litres (Fundira and Henley 2017).

### *Prospects*

SADC countries could save on import costs and earn foreign exchange through the use of liquid biofuels. These benefits could be immediately re-injected into the economy, stimulating sustainable growth and improving the GDP of the countries. This research revealed that Mozambique and Zambia benefit from foreign exchange because they sell liquid biofuel feedstock (molasses) to Malawian companies KCGA and DCGA. The study also revealed that 4% of the transport energy in Malawi comes from liquid biofuels. This implies that the country is already saving 4% on importation costs for fossil fuels and contributing greatly to the fight against GHG emissions (BioRen 2020). Locally produced liquid biofuel could lead to local, national and regional benefits, such as reduced pressure on forests for wood fuel, reduced dependency on oil imports, limited exposure to volatile international prices, and provision of energy for local agriculture, industry and household uses. The research revealed that rural communities in participating countries already use liquid biofuels for lighting, heating and cooking. The development of the biofuel market could decrease food production, increasing the price for food crops, which could benefit local food crop farmers. This in turn could encourage more farmers to venture into food crop production, creating a balance between food crop and biofuel feedstock production.

Liquid biofuel production could enhance general infrastructure development, including roads and electricity, improving local business opportunities. The introduction of modern agricultural practices due to biofuel production can have an overall positive effect on agriculture and food

security. In Zimbabwe and Malawi biofuel companies have contributed to developing schools, roads and clinics. Roads, electricity and telephone infrastructure have been improved in all countries already producing biofuel as a direct result of biofuel development.

### *Challenges*

Land expansion for agriculture has serious consequences, including environmental impacts, such as loss of biodiversity, soil erosion and deforestation. Liquid biofuel production requires high investment capital due to the high technology demand throughout the liquid biofuel value chain (Díaz et al. 2019). The study revealed that Mozambique has invested over US\$1 bn. The development of the biofuel industry could strain the already limited water resources. Countries in SADC do not have enough resources to cover the high investment costs of biofuel production. Developing liquid biofuels in the region does not guarantee low carbon emissions because liquid biofuel production results in massive losses of forested areas. This together with the use of chemicals could result in more pollution and increased GHG emissions.

Several SADC countries have developed policy frameworks to incentivise liquid biofuel demand, including mandates requiring distributors to add fuel ethanol to gasoline. However, the legislative developments to date have been insufficient to spur growth in the industry. The EU has made significant reforms to its liquid biofuels policy, creating barriers to entry, which makes it difficult for SADC countries to export: for example in 2015, the European Parliament passed legislation introducing a cap at 7% of the volume of transport fuels that could come from food or feed crops in 2020. In addition a requirement was imposed that all biofuels be certified by one of around 20 voluntary agencies. This limits the ability of developing world countries to export liquid biofuels to the EU at competitive prices (Pacini and Assunção 2011; Díaz et al. 2019).

### *Mechanisms for addressing the challenges*

Liquid biofuel production involves many stakeholders from diverse sectors and these role players need to work together to drive the sector to greater heights. The study revealed that there is no positive synergy between the liquid biofuel and the food production sectors in most SADC countries. Some stakeholders are 'team food production' while others are 'team liquid biofuel'. Liquid biofuel will not be well developed until these stakeholders unite and try to forge collaboration between the two sectors to coexist. Respondents from all the surveyed countries agreed that capacity building, investment in technology and raising awareness are crucial for solving the problems associated with liquid biofuel production.

Participants throughout the liquid biofuel production value chain must have clear information on the importance of the industry and the need to develop it as a complementary option rather than as competition for food production and livelihood development. The SADC region must have biofuel production guidelines and establish regional incremental targets that will help nullify the challenges. The research identified several strategies that could be employed to reduce the negative impacts associated with liquid biofuel development in the region. These challenges are summarised in Table 3.

Maximising the production potential of liquid biofuel is the main challenge in the SADC region and Africa in general. The countries must consider using second-generation biofuels which require limited land and do not compete with food and feed production. However, this would require investment in technology and human resources. The research revealed that liquid biofuel companies are not using feedstock efficiently. Companies must consider utilising biomass fractions they have discarded and make the best use of the whole feedstock. SADC countries should also consider intensifying the use of non-food high-yield biomass crops, such as jatropha.

### ***Assessment of effect of biofuel production on cropland in forest margins and implications on food security and forest cover loss***

There is a wide range of systems and conditions under which liquid biofuels are produced, including producing from a variety of feedstocks, various production schemes, management practices, land ownership conditions and land use systems. The impact of liquid biofuels on forests depends on the extent of associated land use changes and conversion, and on the specific type of biofuel feedstock. For example, the conversion of natural ecosystems (natural forest and natural grassland) generally induces high losses of biodiversity

**Table 2:** Opportunities, prospects and challenges for biofuel production

Opportunities	Prospects
Availability of labour (many people seeking employment)	Creating more jobs and employment
Free and fertile land availability	Infrastructure development (development of local industries)
Water availability	Improving the economy of the country
High demand for liquid biofuels	Contribute to reduction of greenhouse gases (GHG) emission
Access to factories and export system	Import substitution
High demand for fuel in South Africa given the high number of vehicles and industrial machinery	
Challenges	Coping mechanisms
Pests and diseases	Receives compensation when the land is polluted
High production costs	Develop biofuel policies and frameworks
Low selling price	Include all stakeholders, including the communities
High pollution rates	Use of biodegradable pesticides and herbicides
Inadequate policies	

**Table 3:** Coping mechanisms for liquid biofuel development challenges

Challenge	Coping mechanism
Land and water pollution from application of fertiliser and pesticides	Use of artificial fertiliser to increase yield must be carefully regulated or reduced to prevent emissions of nitrous oxide (N <sub>2</sub> O), a greenhouse gas. More investment must be in the use of tree crops like jatropha. These may reduce N <sub>2</sub> O emissions since they require fewer chemicals than sugar-cane crops.
Inadequate biofuel policies in most SADC countries	There is a need for strong biofuel policy instruments and government commitment to provide a conducive environment for biofuel development.
No government departments dedicated to biofuel production	Countries must put liquid biofuel under one dedicated ministry and financially commit to support its production.
Competition with food security	Food security can be resolved by investing in crop-breeding research and technology for more intensive food production.
Land disputes/land grabbing	Zoning must be done in all the countries to identify and map out potential areas for biofuel investments and potential 'no go' areas.
Water shortages	Countries need to invest in high technology water saving irrigation techniques. Investment in plant breeding to come up with feedstock varieties that use a limited amount of water.
Loss of biodiversity	Proper environmental impact assessments must be conducted, and places of high biodiversity should not be cleared for agricultural purposes.
Lack of funding	Countries must raise funds and resources for infrastructure development for biofuels production, processing, storage, transporting and marketing where biofuels offer such potential.

(Dlamini and Montouroy 2017; Molinario et al. 2017; Nakamya 2022). Using abandoned agricultural land or extensively used grasslands causes relatively lower losses. Biofuel feedstock grown on a large scale in monocultures with heavy fertiliser applications and the use of herbicides has a devastating effect on biodiversity; as observed in the case of sugar-cane and soya bean production (Nakamya 2022).

While most of the SADC countries use agricultural land for biofuel production, evidence exists of land use conversion in the liquid biofuel sector from forest land to agricultural land to increase land for liquid biofuels (mostly annual crops, except *Jatropha*). The research revealed that in Zimbabwe, Tongaat Hulett has earmarked 4 000 ha of forest land to clear for its Kilimanjaro project. The land will be developed to support a total of 200 smallholder farmers. The study discovered that another project in Mbire has also earmarked over 9 000 ha of forest land to clear for sugar-cane production in the district. Green Fuel in Zimbabwe acquired an undisclosed amount of land that belonged to 116 smallholder farmers. There have not been any complaints about land grabbing from the general community in Malawi and Mozambique. During the interviews respondents indicated that most smallholder feedstock farmers willingly committed their land. These farmers own between 2 and 5 ha of land inherited from their forefathers. The farmers have alternative land for producing food crops and they are financially rewarded by the stable biofuel market.

#### **Determination of forest cover to indicate deforestation and degradation**

Most rural people in the SADC region rely largely on forests for shelter, food, energy, construction materials, employment and other forest products for domestic consumption and trade (Moon and Solomon 2018). In relation to ecosystem contribution, forests and trees provide land cover in watersheds to reduce erosion and flood risk, and to protect coastal areas from climate-related threats. Forest resources in the SADC region are extensive and diverse, covering an estimated area of 394 million ha (representing 41% of the region's total land area). Plantation forests account for only about 3.3 million ha of forest cover in the SADC region (Naidoo et al. 2013). Table 4 shows the distribution of forest as a percentage of total SADC forest cover (39 million ha) as adapted from Naidoo et al. (2013). The distribution is aggregated by country.

DRC, Angola, Zambia, Tanzania and Mozambique have the largest forested areas in Africa. There is a great chance of losing most of these forests to liquid biofuel production. The study did not get details on the rate at which liquid biofuel production is having a negative effect on forest areas. However, there are reports that forest areas are used for liquid biofuel feedstock cultivation in Mozambique, Malawi and Zimbabwe. *Jatropha* production is the major competitor for forest areas.

According to Ngcobo and Jewitt (2017) and FAO (2020), between 2010 and 2020 Africa had the largest annual rate of net forest loss at 3.9 million ha. In the same reporting period the SADC region had a total forest loss of approximately 0.46% (1.8 million ha). From 1990 to 2015 forest area (as a portion of total land area) was reduced by 3.5% (Keenan et al.) In this period a biomass loss of 55% was reported for

**Table 4:** Distribution of forest as a percentage of total SADC forest cover (39 million ha)

Country	Forest cover (%)
Mozambique	10.0
Malawi	0.8
Zimbabwe	4.0
South Africa	2.3

the Miombo woodlands ecosystem across Angola, Zambia, Tanzania and Mozambique (FAO 2020). This study revealed that the SADC region is losing most of its forest through agricultural expansion (food crop production); extraction of fuel wood, hardwood and timber; conversion of natural forest to plantations; infrastructure development; and overstocking with domestic animals.

#### **Assessment of competitiveness of African biofuels in the international market**

The production costs for biodiesel in the region are estimated at 0.539 US\$ l<sup>-1</sup> while it costs about 0.97 US\$ l<sup>-1</sup> to produce bioethanol production from sugar-cane (Sekoai and Yoro 2016; SARDC 2017b). This is extremely high compared to the other regions, including Brazil. For example, it costs about 0.19 and 0.25 US\$ l<sup>-1</sup> to produce biodiesel and bioethanol respectively in Brazil. In terms of quality SADC liquid biofuels strive to meet international standards. This study revealed that Malawi's bioethanol and biodiesel are of 99% quality. The quality standards used by both companies are ISO 9001 for quality ISO 14001 for the environment and ISO 45001 for safety. Malawi, South Africa Zambia and Zimbabwe are the only SADC countries that adhere to these quality standards. There is a need to stipulate the quality standards in a SADC biofuel framework so that all countries in the region can comply. Developing the biofuels industry in Africa will necessitate the development of technologies to ensure that this market is strengthened by improving energy yields. This will make it economically competitive with petroleum oil (UNEP 2017).

#### **Identify relevant policy regulatory and institutional frameworks**

The development of a viable liquid biofuels sector requires a strong supportive regulatory and institutional framework (in terms of policy and legal provisions) relevant to the sustainable production processing transport and consumption of liquid biofuels in the context of changing climate. This will ensure that measures are put in place to harness the contribution of the sector to socio-economic development while safeguarding rural livelihoods and the ecosystem. Comprehensive policies help encourage sustainable approaches, reduce barriers, and highlight information or funding needs. The research revealed that the only SADC countries with biofuel policies are Mozambique (Development of New and Renewable Energy) and South Africa (South African Biofuels Regulatory Framework). However, these policies have several gaps, making them inefficient and lacking the cutting edge needed to positively influence the development of biofuels (Table 5).

South Africa, Botswana and Mozambique have completed

agricultural zoning, and Zambia and Tanzania have completed food crop mapping. Although Malawi is one of the early adopters of the liquid biofuel concept the country has yet to develop a biofuel policy and complete agricultural zoning. Zoning is important to ensure that there is no conflict between the different land uses. The study revealed that despite the lack of policy and zoning there have not been any serious land use conflicts emanating from liquid biofuel production.

The main challenge faced by the liquid biofuel sector is competition with food security and fear of perpetuating poverty. SADC countries have not successfully formulated strategies and policies to allow liquid biofuel and food production to coexist without challenges. The poverty reduction strategy papers (PRSPs) of most countries do not address liquid biofuel production (Melin et al. 2022). Almost all energy policies have policy statements on general biofuel development without concrete strategies and institutional frameworks for implementation. Trade policy and investment incentives in Africa are still not conducive to attracting domestic and international investments in biofuels (Fundira and Henley 2017; SADC 2017).

According to SADC (2017) and Biofuel Digest (2018), well-structured policies should have the following characteristics:

- designed to promote rural development
- geared to the objectives of energy security
- able to attract appropriate investments
- based on sustainable land use

The policies have not outlined strategies for the development of the biofuels sector. Only seven of the 16 states belonging

to the SADC have incorporated incentives for promoting renewable energy products, including biofuels (Table 6). Other countries in the region need to act and put in place the necessary incentives to promote liquid biofuel production, and could use the seven SADC countries as benchmarks for this activity. These incentives include capital/subsidy grants, investment and tax rebates, and energy production payment (SADC 2017). The actual values of the incentives are different for each country. SADC has not stipulated uniform incentives for renewable energy promotion.

Our research findings align with those of other authors (Fundira and Henley 2017; von Maltitz and van der Merwe 2017) regarding the discrepancies and gaps in the biofuel policies and guidelines in the region. The following gaps were identified during our research and are backed by different authors.

- Liquid biofuels are discussed within a group of renewable energy sources. That is, the countries do not have standalone biofuel policies. For example, Malawi's national energy policy approved in 2003 discusses ethanol among liquid fuels. This makes it difficult to commit fully to the development of the industry, mostly with regard to financing.
- Some countries have not finalised national energy policies yet continue implementing renewable energy projects. For example, Mozambique has already adopted preliminary regulations to foster large-scale biofuel production without finalisation of the national energy policy.
- Liquid biofuel production is not fully supported by SADC governments. For example, in Zambia and Malawi the private sector foreign companies and non-governmental organisations are responsible for encouraging farmers to

**Table 5:** Biofuel framework or selected SADC countries

Item	Country			
	Malawi	Mozambique	South Africa	Zimbabwe
Agriculture zoning	No	Yes	Yes	No
Quality standards	Yes	No	Yes	Yes
National Biofuel Policy	No	Yes	Yes	No
Investment centre for biofuel	No	Yes	No	No

Source: adapted from SADC 2017

**Table 6:** SADC renewable energy incentives

Country	Regulatory incentives					Financial		
	Feed-in-tariff/payment	Net metering	Biofuel obligation	Grid code revisions	Tradable credits	Auctions	Subsidy, grant, rebate	Tax breaks
Botswana	✓					✓		
Mozambique*	✓		✓	✓				
Namibia	✓	✓				✓		
South Africa*	✓	✓	✓	✓	✓	✓	✓	✓
Tanzania	✓						✓	
Zambia	✓		✓	✓			✓	✓
Zimbabwe*	✓	✓	✓	✓		✓	✓	

Source: adapted from SARDC 2017a ; \* = country represented in this study

grow crops for biofuel production. So there is a need to establish a regulatory authority that can be responsible for fundraising for biofuel development.

- In countries such as Malawi, the development of the liquid biofuels sector value chain has contributed massively towards economic development but it is left out of the Malawi National Export Strategy.
- African trade policies encourage bilateral and multilateral trade agreements between Africa and nations outside the continent through the African Growth Opportunity Act (AGO). These agreements place local people at risk of losing their land resources as foreign investors flock to the continent. For example, foreign investors from Europe and Asia have already started to acquire land in Africa for liquid biofuel development in Tanzania, Zambia and Malawi. There is a need for appropriate policy and regulatory frameworks to avoid local people being evicted from their land and to protect the natural forests.

## Conclusion

Based on the findings of this research, SADC countries have great potential for liquid biofuel expansion. The countries have enough suitable landholdings to maintain a balance between food production and liquid biofuel development. The government and private companies have enough land already committed to developing the liquid biofuel industry. However, there is a need to invest more in infrastructure and technology for the sector to be more efficient. The research revealed that a larger percentage of the unemployed youth are skilled and some have been trained in various aspects of the agricultural industry (e.g. crop production, irrigation, land management, plant breeding, livestock production, etc.). These people could be deployed throughout the liquid biofuel production value chain, improving production efficiency while solving the challenge of youth unemployment. Investment in advanced agronomic practices and research on efficient production strategies are necessary. Mozambique is already breeding high-yielding sugar-cane varieties, a practice that should be replicated throughout SADC. SADC countries should consider using second-generation biofuel feedstock. Currently, South Africa is the only country piloting this in the SADC region (at a low level). Except for South Africa the SADC countries do not have sufficient national markets for liquid biofuel. However, South Africa is a proven potential anchor market for the SADC region, and the accessibility of its market should encourage SADC countries to move in the same direction. Since the industry is poorly developed, countries must first focus on satisfying national markets. The European liquid biofuel market is currently unfavourable but could be penetrated in the near future. Although biofuel production holds enormous potential for boosting national economies, countries should thoroughly investigate the potential negative economic and environmental effects before fully embracing biofuels. Only two countries in the SADC region have biofuel policies and this indicates a huge gap, given that a policy framework is crucial for the development of any industry.

Liquid biofuel production is yet to reach an advanced stage in the SADC region, meaning that the contribution towards loss of forest and land cover is low. The region's

greatest contributors to forest loss include human settlement, uncontrolled wildfires, agriculture (food crop production) and development of industries. Nevertheless, development of the liquid biofuel sector could result in a high loss of forested areas and land cover in the near future. On the other hand, liquid biofuels can also contribute towards forest conservation as more people apply them to domestic uses such as cooking and heating, which is currently dominated in rural communities by the use of fuelwood for cooking and heating, placing a heavy demand on forests. The contribution of liquid biofuel towards minimising GHG emissions has not been adequately quantified in the SADC region as most of the countries in the region do not have the capacity in terms of technology and skills.

## Recommendations

Countries in the SADC region can:

- Allocate land for agriculture, settlement and industrial development to avoid loss of forest and conflicts between the different land uses, particularly liquid biofuel and food production;
- Establish mechanisms and strategies to facilitate effective skills and technology transfer between countries;
- Formulate biofuel policies that target the entire liquid biofuel production value chain so that the production of liquid biofuels can follow an integrated pathway;
- Develop a unified strategy that ensures effective learning from the liquid biofuel pioneers (i.e. Brazil, USA and Germany);
- Collaborate and study the current situation taking into account the obstacles and constraints, and develop biofuel policies that will be comprehensive; and
- Develop databases that feed into a shared regional liquid biofuel database.

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