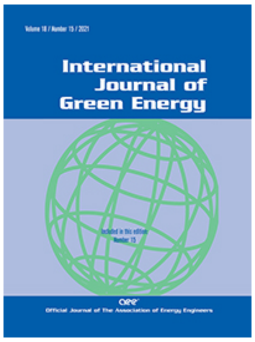

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# Status of biodiesel research and development in Kenya

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**ABSTRACT**

Research has established that biodiesel performs well in engine and is considered to be fuel with low carbon emission. This gives it a possibility of replacing it with fuel obtained from fossil sources and whose amount is dwindling as they are not renewable. Biodiesel development in Kenya has begun to receive high levels from the government due to continued rise in the cost of fossil fuels. Various stakeholders in biodiesel industries formed the National Biodiesel Committee in January 2006 under the Ministry of Energy to have a collective voice in promoting policies such as blending mandates, tax mandates and production subsidies. This review therefore, focus on status of biodiesel research and development in Kenya. Among the areas of focus include development of biodiesel in various Kenyan institutions, impact of jatropha on Kenya's biodiesel plans, status of biodiesel research using indigenous jatropha oil, physicochemical properties of *Jatropha curcas* seed oil, formulation of biodiesel policy, possibility of harnessing indigenous algae for biodiesel production and the possibility of re-using waste vegetable oil and animal fat for biodiesel. The various works reviewed revealed that the energy requirement of Kenya can be met and the looming energy crisis averted.

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Biodiesel; Kenya; energy; fuel; transesterification reaction

## 1. Introduction

Biodiesel, monoalkyl esters of long-chain fatty acids is considered the most suitable substitute for diesel (Ramos et al. 2019). The benefits of biodiesel include nontoxic, biodegradable, clean energy, reduction in global warming, insignificant content of aromatic compounds and sulfur, higher cetane content and flash point (Munyao 2016; Duda et al. 2018; Ayoob and Fadhil 2019; Otta 2016). Biodiesel also improved lubrication capabilities and reduced dangerous exhaust emissions relative to petrodiesel (Knothe and Razon 2017)

Studies indicate that biodiesel production and use in Kenya is still at an early stage with little research done in the sector, despite the country's potential to produce the fuel (Otieno et al. 2018). This hinges Kenya's effort and goal of using biodiesel as a replacement for traditional diesel and other fossil fuel by 2030. The few studies carried out on biodiesel produced from Kenyan feedstocks include *Croton megalocarpus* and yellow oleander (Hunsberger 2016 & Otieno et al. 2018). Other researchers have identified oils such as *Moringa oleifera* (Olubuade 2015) *Calodendrum capense, Croton megalocarpus, Jatropha curcas, and Cocos nucifera* (Fekadu, Feleke, and Bekele 2019). Others have however, mentioned castor oil and *Grain amaranth* as other oils in Kenya (Nyika 2020).

Very little study has been done on the production of biodiesel and tests from African countries such as Kenya. Kenya currently, has no known commercial deposits of fossil fuels regardless of government's attempt to explore potential locations. Consequently, all liquid fuels that are brought into the country is expensive and absorbs a significant portion of the foreign exchange of the world (Mazumder 2020 & Munyao 2016).

The use of crops such as sunflower oil, safflower oil, corn oil, coconut oil, palm oil and soybean oil as a source of biodiesel feedstuffs conflicts with their use as food. It cannot thus efficiently fulfill the world's demands for biodiesel. The application of vegetable or plant oils have some adverse effects such as increased viscosity and low volatility which can lead to partial ignition in compression ignition engines and henceforth, carbon deposition. Extensive research has been conducted to develop biodiesel derivatives that have properties similar to those of petrodiesel (Nyika 2020 & Onuh and Inambao 2016b).

The main aim of this review is to examine the current status of biodiesel research and development in Kenya. It seeks to answer the following research question: what is the status of biodiesel research and development in Kenya? Among the areas of highlights in this review include development of biodiesel in various Kenyan institutions, the impact of Jatropha on Kenya's biodiesel plans, status of biodiesel research using indigenous Jatropha oil, physicochemical properties of *Jatropha curcas* seed oil, formulation of biodiesel policy, harnessing indigenous algae for biodiesel production and the possibility of re-using waste vegetable oil and animal fat for biodiesel.

## 2. Biodiesel from transesterification reaction

Transesterification is the process of converting large triglycerides (TGs) to form short-chain alkyl ester molecules having size and physical properties which are the same as those of

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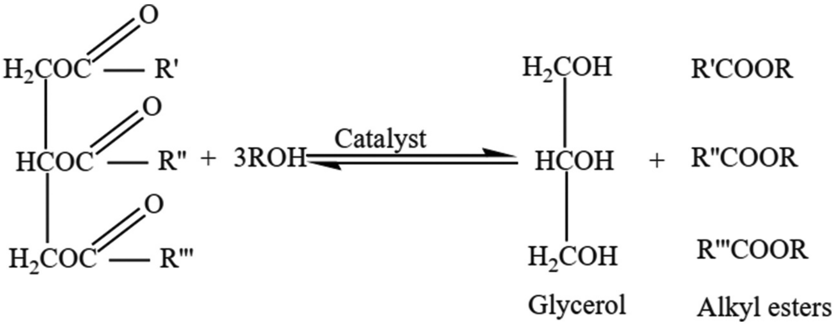

$$H_2COC(=O)R' + HCOC(=O)R'' + H_2COC(=O)R''' + 3ROH \xrightleftharpoons{Catalyst} H_2COH + HCOH + H_2COH + R'COOR + R''COOR + R'''COOR$$

**Figure 1.** General equation for transesterification (Montcho et al. 2018).

petrodiesel (Dash and Lingfa 2017). Each molecule of a triglyceride stoichiometrically, requires three molecules of alcohol to reach complete reaction and additional alcohol is usually added to change equilibrium of the reversible reaction for enhance yield. The mole ratio used is dependent on the oil feedstock, the catalyst employed, time of reaction and temperature. Some of the commonly used alcohols for transesterification include methanol, ethanol and propanol. The biodiesel produced does not depend on the nature of alcohol, but rather the cost of the feedstock (Chavan et al. 2015).

Excess amount of alcohol results in a rise in emulsification and separating glycerol turns out to be a challenge. The suitability of most oil should be through experimental determination of every oil feedstock in regards to alcohol ratio (Demirbas and Edris 2017). Ester bonds are initially broken down in the process of transesterification and this is preceded by cleavage of hydroxyl bonds. However, during esterification the breaking of the hydroxyl bond results in glycerol formation as a co-product in transesterification and esterification (Montcho et al. 2018).

Various catalysts are used to carry out transesterification. Some of these include alkali, acid or enzyme (lipases) that can promote hydrolysis of triglyceride to form fatty acid alkyl esters (FAAE) and glycerol. Purification of biodiesel from glycerol is done by separating the steps which entails washing using warm water for a number of times (Gumba et al. 2016). The general chemical equation for transesterification is shown in Figure 1 above.

## 3. Prospects of biodiesel for Kenya's economy

Analysis of economy for indigenous oils in Spain revealed that the major factor in biodiesel production when compared with mineral diesel is the cost of virgin vegetable oil (Callegari et al. 2020; Laurens, Chen-Glasser, and McMillan 2017; Prabhu, Venkata Ramanan, and Jayaprabakar 2018). Related economic studies also showed similar revelation with the solution being harnessing the vegetable oil which is obtained from indigenous vegetation growing on marginal land (Takahashi et al. 2015 & Nyika 2020). In regards to this, India has successfully exploited the Jatropha plant for the production and consumption of biodiesel of low cost in the last decade (Dalemans et al. 2018 & Jingura and Kamusoko 2018). Different countries have endeavored to make use of microalgae as feedstock in the production of biodiesel and outcomes have been successful (Bošnjaković and Sinaga 2020). However, Kenya appeared to remain behind the scenes in a global biodiesel game (Mukabane et al. 2018).

Kenya is similar to other developing countries that are still relying on fossil fuel which are imported. Despite having dominancy in sources of energy, there is a limitation in conventional fossil fuel which is not equally distributed and yet a lot of crucial reserves are located in areas with political instabilities (Ndiritu and Engola 2020 & Sergi et al. 2018). Huge barrels of oil are imported to Kenya. Kenya relies on natural resources in the generation of 60% of the primary demand for energy. The importation bill of fuel is high and burdensome to the gross domestic product of the country. At the same time, excess extraction of natural resources for energy supply results in degradation and biodiversity loss (in which the cases are extreme). Besides, using energy sources such as firewood is a threat to life and environment. Production of gases such as carbon monoxide, benzene, nitrogen oxide causes pollution which negatively impacts the environment. Price volatility and unreliability supply of the fossil fuels makes them not favorable choice of energy (Tracy 2015, & Kywe and Oo 2016)

These challenges in energy negatively impact on the environment and calls for exploration to other friendly and sustainable sources of energy. Except for the high cost that entails accessing renewable sources such as solar and wind, biofuel has been said to be the best substitute with a lot of potential in solving Kenya's energy crisis. Biofuels are among the most economical for tropical countries due to its comparative advantage in terms of its cultivation (Mosonik et al. 2018, Sharma, & 2015; Pueyo 2018). Some of other feedstocks including *Ricinus comminis, Croton megalocarpus, Jatropha curcas* are under evaluation for production of biofuel. The results are however, conflicting in terms of their potential as feedstocks for commercial purposes. Nonetheless, the energy crisis should be solved through biofuel as well as the provision of positive energy balance for the benefit of the environment (Mosonik et al. 2018; Hunsberger 2016 & Dharma, 2016) .

Few works have highlighted the prospect of biodiesel for Kenya. In most of these works, the possibility of producing biodiesel on a large scale has been looked at extensively. Emphasis has been on the requirement of the production of biodiesel for sustainable development and to help in reduction in dependency on imported fuel (Mosonik et al. 2018; Hunsberger 2016 & Curcas, 2016) .

## 4. Research and development on biodiesel in various Kenyan institutions

Biodiesel sector in Kenya is still at the infant stage. Non-governmental organizations (NGOs) and private sectors have been involved in the promotion of biodiesel and were involved in the identification of growth of feedstock which is considered to be the major income generation for the people in marginal places. Majority of these organizations including Vanilla Jatropha Development and Green Africa Foundation are promoting jatropha to the farmers, especially in the arid and semi-arid areas. This is because its believed that Jatropha can perform well in harsh environmental condition and needs less input and care. The seeds are not edible and this ensures it does not compete with food. Even though Jatropha has been promoted mostly, other feedstocks such as croton and castor have also been considered (MITEI 2017; Hunsberger 2016 & Munyao 2016).

There has been many controversies on the growth of the sector. This was after the farmers abandoned cultivation of Jatropha due to a poor harvest and limited market. There have been concerns raised by many regarding the way Jatropha plant has been promoted without adequate research on the crop's agronomical requirement and the seed germplasm. The absence of the processing infrastructure and policy and legal framework exacerbated the situation since the farmers who had harvested the seeds lacked the technical capacity for processing them to oil for good market (Munyao 2016 & MITEI 2017)

The entry of the government into the seen was late and since then has been involved actively in trying to save the situations. This has been through commissioning of study in partnership with GTZ in 2008 with the title, "A Roadmap for Biofuel in Kenya; Opportunities and Obstacles" facilitating the drafting of the biofuel policy, biodiesel strategy and bioethanol strategy in the last 3 years. The biodiesel association of Kenya was formed in 2008 and was made up of major stakeholders such as NGOs and research institutions where the ministry officials represented the government. The aim was to help in the promotion and coordination of all activities that are related to biodiesel (Mukhwana et al. 2016).

Zijani launched Kenya's first biodiesel research and development refinery in Nairobi in November 2014. The refinery had the capacity of manufacturing up to 13,000 l per year. The expectation was to generate 48,000 l of biodiesel each year beginning May 2017. The project was completed in 2016. There is however, advance biodiesel plant in Nairobi that is capable of producing 50,000 l of biodiesel each year. This was Kenya's first plant that was dedicated to producing biodiesel from cooking oil. It has resulted in Zijani pushing closer to achieve a 100% recovery of its resources through generation of biodiesel that saves more than 95% of the green gas emission related to fossil fuels (Barasa 2018 & KIP, 2016).

Biodiesel development in Kenya has received much attention from the government due to the continued rise in the cost of fossil fuels and the increasing awareness on environmental concerns. The attention has occasioned the formation of the National Biodiesel Committee which is under the Ministry of Energy as provided by the Energy Act (2006) (Mwihaki 2016).

There are also other ongoing research activities on biofuel production, utilization and vegetable oil sources including crop agronomy. It became necessary to design a regional biofuel course whose curriculum responds to emerging opportunities for middle-level practitioners. The course was to be administered jointly by both universities and users as a way to enhance the technology transfer and capacity of practitioners in public and private sectors (Jingura and Kamusoko 2018).

### *4.1. Impact of Jatropha Biodiesel on Kenya's Biodiesel plans*

The effort of Kenya to harness the Jatropha plant for the production of biodiesel is nothing short of praiseworthy. Research and development at the moment are underway. Despite these negativities, a conclusion was made that jatropha could solve the insecurity in the energy sector and for the benefits of the rural livelihood as well as protection of the environment. In addition to being a potential cash crop, there are some prospects in it making Kenya self-reliance in terms of energy supply with potential economic, social and energy secured. Existence of high demand by the locals and farmers who are open-minded in Kwale District in Kenya gives Jatropha a chance of proving its potential to alleviate livelihood in rural areas through productions and use (Mwihaki 2016, KI P, 2016 & Newell and Phillips 2016) .

#### *4.1.1. Status of Jatropha cultivation for biodiesel production*

Even though Jatropha is not native to Kenya, the species appears to have been brought into the country about a century ago (Munyao 2016). Due to its natural stand in Kenya, the tendency to spread have not been noticed and to find the young Jatropha trees is rare (Hunsberger 2016; Nyika 2020). In Kenya, Jatropha is mainly grown in the Rift Valley (Kajiado, Namanga, Nakuru, Naivasha, and Marakwet), Nyanza, Central (Thika), Eastern (Kitui and Meru) and the Coast (Malindi) provinces. In East Africa, Tanzania is said to have made the most significant strides in terms of growing the fuel tree on a large scale. Meanwhile, Kenya is said to be well ahead of other African countries in research on Jatropha (Ma, 2016).

Government policy plays an important role in fostering the growth of the biodiesel industry in Kenya. Active government support has been essential in every country where biodiesel and other biofuel industries have successfully been established. Government policy influences the returns that can be generated from different value chains and thus the potential returns to different types of actors. Government has an interest in reintroducing power alcohol as a motor fuel in its long-term policy to enhance the security of supply if it could overcome the problem of competitiveness in the market. However, its (government) has taken a cautious approach toward reconsidering support for the biofuels industry due to the experience of previous policy failures. In Kenya, various stakeholders in biodiesel industries formed the national biodiesel committee in January 2006 under the Ministry of Energy to have a collective voice in promoting policies such as blending mandates, tax mandates and production subsidies (Roux et al., 2016 & Mukabane et al. 2018).

### 4.1.2. *Status of biodiesel research using indigenous Jatropha oil*

The *Jatropha curcas* plant is a drought resistant crop that develops deep taproot and shallow roots allowing it to resist and control soil erosion. The leaves are smooth (4–6) lobed and 10 to 15 cm in length and width. It produces about 2–4 kg/seed/tree/year. In poor soils, the yields have been reported to be about 1 kg/seed/tree/year. The oil yields of *Jatropha curcas* is reported to be 1590 kg/ha (Prabhu, Venkata Ramanan, and Jayaprabakar 2018 & Dharma et al. 2016). The major fatty acids in *Jatropha curcas* seed oil are oleic, linoleic, palmitic and stearic acids. The properties of the oils obtained from this plant are presented in Table 1 (Wahyudi et al. 2019).

The cost of production of biodiesel from Jatropha will arguably vary from location to location due to labor charges, land acquisition and policies in place. Hunsberger (2016) presented a strong case for biodiesel production from Jatropha. Given that 500 workers working on a 1,500,000 ha, approximately 2,250,000 L of oil can be generated. The expected revenue can be computed using the labor cost applicable to the region of interest. On land use, it should be noted that it costs less to grow Jatropha. Thus it does not require expensive crop rotation or fertilizers. As a result, several organizations in Kenya are involved in the production while some are involved in the testing of biodiesel from ***Jatropha curcas*** oil. The main thrust behind the work has been a high oil content in the seeds (ca 30% to 40%) (Asnake et al. 2020; Munyao 2016) as well as the presence of anti-nutritional chemicals in the oil that tend to make it inedible (Rodrigues et al. 2016).

### 4.1.3. *Jatropha oil produced from the various regions in Kenya*

According to studies by Tracy 2015, accession with the highest oil yield per weight was from Meru with 38.8% oil content while those from Funyula and Oyugis were 28.4% and 27.0%, respectively. The least was from Kibwezi with 23.1% (Table 2). According to Munyao (2016), the expected oil yield range for *Jatropha curcas* seeds that can be processed to high-quality biodiesel fuel is about 27% to 40% (average 34.4%).

**Table 1.** Highlight of properties of *Jatropha curcas* oil (Wahyudi et al. 2019).

| Property | Parameters status | Remark |
|---|---|---|
| Kinematic viscosity | Very high | The kinematic viscosity of crude *J. curcas* oil can be reduced to about 82% after transesterification and amount to be 4.8 mm$^2$/s using preheating, blending, ultrasonically assisted methanol transesterification and supercritical methanol transesterification. |
| Pour point | Low in comparison to edible oils biodiesel High | It may be used in some four season's countries |
| Iodine value | High | Indicated higher unsaturation of fats |
| Flashpoint | Higher in comparison to diesel | Due to a higher flash point, jatropha oil has certain advantages over diesel, such as greater safety during storage, handling, and transport. |
| Calorific Value | high in comparison to the diesel | Jatropha has about 90% calorific value compared to diesel |
| Cetane Number | high as compare to that of diesel | Pure Jatropha oil can be used directly in engine without converting to biodiesel |
| Acid number (Mg KOH g$^{-1}$) | Slightly higher than that of diesel | High acidity of pure Jatropha oil as compare to diesel leads to damage in engine's rubber parts |

**Table 2.** Quantity of oil from *Jatropha curcus* produced from the various regions in Kenya (Munyao 2016).

| Region | Percent yield (%) |
|---|---|
| Kibwezi | 23.1 ± 0.03 |
| Oyugis | 27.0 ± 0.02 |
| Meru | 38.8 ± 0.2 |
| Funyula | 28.4 ± 0.1 |

Values are mean ± SD of triplicate determinations triplicate

### 4.1.4. Physicochemical properties of *Jatropha curcas* seed oil

In Munyao (2016) study, *Jatropha curcas* accessed from Kibwezi showed the lowest moisture content (0.08275 ml) with those accessed from Funyula revealing higher levels (0.18525 ml) (Figure 2). Moisture is a chemical contaminant which is mixed with lubricating oil such as Jatropha oil and it is the primary cause of most engine failure; hence the moisture content reported herein was lower than 0.2% (Kywe and Oo 2016).

### 4.1.5. *Preparation of Jatropha and diesel oil blend*

From studies of Prabhu, Venkata Ramanan, and Jayaprabakar 2018 & Takase et al. (2015), it is evident that dilution or blending of vegetable oil with other fuels like alcohol or diesel fuel would bring the viscosity close to specification range. Therefore, Jatropha oil was blended with diesel oil in varying proportions to reduce its viscosity close to that of the diesel fuel. The essential physical and chemical properties of the biodiesel thus prepared are given in Table 3. The various blends were stable under normal conditions.

## 4.2. *Kenyan Universities research*

The University of Nairobi, Jomo Kenyatta University of Agriculture and Technology (JKUAT) and Kenyatta University are carrying out different aspects of research work on Jatropha and biofuel. The Chemistry Department at the University of Nairobi provides biofuel policy leadership to the National Biofuel Committee (NBC). The proposed road map for the biofuel strategy/policy is mainly based on this work (Achard 2017 & Mukabane et al. 2018). It is crucial to expand the membership of the NBC and also strengthen its strategic leadership through the Ministry of Energy to comprehensively address the broad issues that entail the process of biofuel strategy/policy formulation. Without the Ministry of Energy acting like a champion, biofuel policy and strategy formulation will be nonstarters and will end up as disjointed activities without any impact at the national level (Munyao 2016).

Jomo Kenyatta University of Agriculture and Technology (JKUAT) undertook joint research in collaboration with industries and other institutions such as Kenya Organic Products Ltd. JKUAT analyzed Jatropha oil and its by-products to

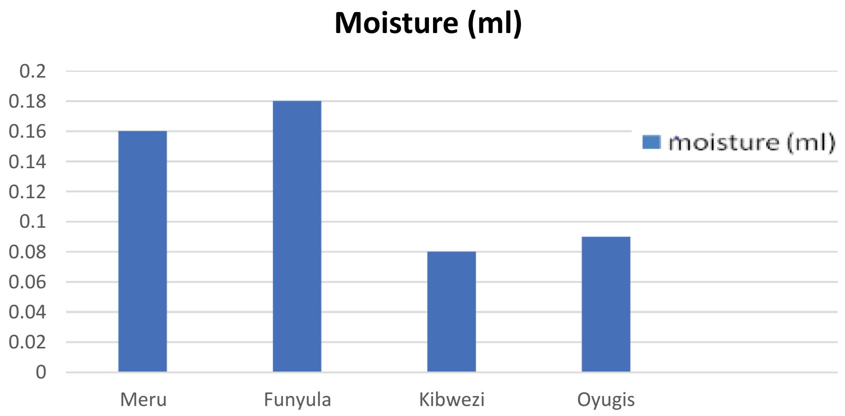

**Figure 2.** Moisture content of Jatropha cultivated in different areas of Kenya (Kywe and Oo 2016).

**Table 3.** Physical and chemical properties of diesel and Jatropha oil blend (Prabhu, Venkata Ramanan, and Jayaprabakar 2018 & Takase et al. 2015).

| Properties Diesel Jatropha curcas oil | | |
|---|---|---|
| Density(gm/cc), 30°C | 0.836–0.850 | 0.93292 |
| Kinematic viscosity(cSt), 30°C | 4–8 | 52.76 |
| Cetane No. | 40–55 | 38.00 |
| Flash point, °C | 45–60 | 210.00 |
| Calorific value, MJ/kg | 42–46 | 38.20 |
| Saponification value | - | 198.00 |
| Iodine No. | - | 94.00 |

provide guidelines for production and utilization (Hunsberger 2016). For example, based on sunflower data from South Africa, a study has found that a plant capacity of 8,000 l per day will require about 16 tons of feedstock per day. This amount could be supplied by 800 farmers cultivating 5-ha plots which would create 16,000 field jobs and 15 plant jobs per day. Consequently, the 1.8 million required to meet 4% of diesel consumption per day has the potential to generate 16,150 jobs (Chavan et al. 2015; Onuh and Inambao 2016a; Republic of Kenya Ministry of Energy and Petroleum 2016) .

## 5. Harnessing of indigenous resources for biodiesel production

### 5.1 Contributions of Energy Regulatory Commission and National Biofuel Committee

The Kenyan Government created the Energy Regulatory Commission under section 4(1) 2006 in 2008 with the responsibility for economic and technical regulation of electric power, renewable energy and downstream petroleum subsector. The Ministry of Energy has been coordinating the plethora of ministries and departments. It acts through the creation of National Biofuels Committee which brings together research institutions, universities and other public sector entities as well as private sector and NGOs that are involved in biodiesel development in Kenya. Kenya's draft bioethanol and biodiesel strategies identified the opportunities that biodiesel development can bring in terms of environmental benefit of blending biodiesel into conventional fuels and the diversification of energy sources. The focus on Kenyan's strategy is assisting smallholders' farmers in producing Jatropha, which can be achieved through public-private sector partnerships. On the policy front, the Ministry of Energy has convened a team in National Biofuel Committee (NBC) which comprises representative from the petroleum industry, ministries, agricultural producers and NGOs. The Committee has drafted a biodiesel policy strategy with nearly exclusive focus on Jatropha. While this is on-going, researchers in universities and other institutions are engaged in laboratory research on appropriate technical aspects of production and analysis of biodiesel fuel (Republic of Kenya Ministry of Energy and Petroleum 2016 & Roux, Lamotte, and Achard 2017) .

### *5.1. Collaboration with other local research institutions*

Technology for biofuel production already exists in Kenya. Virtually no practical experience exists in Kenya regarding biodiesel manufacturing. However, Kenyan Industrial Research Development Institute (KIRDI) has begun to research and experiment with biodiesel production technology on a very small scale. Expertise in biofuels production can be transferred along with the technology needed for manufacturing. The production process and the technology required are well understood and not particularly difficult to emulate. Machinery and equipment can be fabricated locally once the scale of biofuels production justifies the capital cost of manufacturing plants (Republic of Kenya Ministry of Energy and Petroleum 2016 & Munyao 2016).

Kenya Forestry Research Institute (KEFRI) has also been researching on various tree and shrub species to ascertain their potential for biodiesel production. The priority of the species is Jatropha, Croton, Yellow oleander and Pongamia. Though most of the research is now focus on Jatropha, various research project been carried out on Jatropha are encouraging though it should be better coordinated among the participants and donors to avoid overlap and to take advantage of the relative strengths of the various projects. Other crops such as castor and croton are mentioned in the document. In some respect, these other crops may present a better opportunity for large-scale production within short to medium term because they can produce large quantities of feedstock within a season (Republic of Kenya Ministry of Energy and Petroleum 2016) & Mukabane et al. 2018).

Kenya Agricultural Research Institute (KARI) is said to be the leading national agricultural research institution in the

Table 4. The cost of various biofuel feedstock (MoE, 2016 & KIP, 2016).

| Feedstock cost | Castor [a] | Coconut[b] | Cotton[e] | Croton[d] | Jatropha[e] | Rapeseed[f] | Sunflower[g] |
|---|---|---|---|---|---|---|---|
| Cost of Seed (Ksh/L) | 20,000 | 29,327 | 20,000 | 15,000 | 15,000 | 26,000 | 31,984 |
| Oil Content | 40% | 65% | 13% | 30% | 30% | 35% | 37% |
| Unrefined Oil (Ksh/L | 44.64 | 40.28 | 137.36 | 44.64 | 44.64 | 66.33 | 78.24 |
| Seedcake Revenue | | | | | | | |
| Animal Feed (Ksh/L) | | 2.33 | 89.63 | | | 19.90 | 24.85 |
| Biogas (Ksh/L) | 6.04 | | | 9.40 | 9.40 | | |
| **Total (Ksh/L)** | 38.60 | 37.95 | 47.73 | 35.24 | 35.24 | 46.43 | 53.3 |

country. It runs research programs in food crops, horticultural and industrial crops. Other systems including livestock and range management, water management and socioeconomics are also included. KARI promotes sound agricultural research, technology generation and dissemination of food security through improved productivity and environmental conservation. KARI Katumani Center in Machakos is involved in germplasm collection, evaluation and agronomic research. Conservation efforts by KARI have led to the preservation of five accessions for Jatropha – from Nyanza, Makueni, Kajiado and Marsabit into the National Gene Bank of Kenya (Ministry of Energy and Petroleum, & Sustainable Energy for All 2016 & Mokveld and Eije 2018).

### *5.2. Commercial ventures*

The cost of biofuel feedstock has to do principally with the price per ton of oilseed, the percentage of the oil that can be extracted from the seed (known as "oil content") and the revenue that can be collected from the seed cake that is leftover after the oil has been extracted. For edible crops such as coconut, cottonseed, rapeseed and sunflower the seed cake can be sold as animal feed. For non-edible crops such as castor, croton and jatropha, the seed cake can be converted into bioenergy or used to power plants. The estimated price of seed is based on discussions with the farmers, data from the Ministry of Agriculture and KARI. Revenue from the seed cake expected from the market price of the animal feed is the discounted value of biogas that could be produced. The added capital cost of biogas digester is included for the three feedstocks for which biogas revenue is projected (Table 4) (Munyao 2016).

Croton and Jatropha are the cheapest feedstock although, they take the longest to mature and thus are potentially less attractive for farmers, primarily if they cannot readily be financed for a long-term investment (Mosonik et al. 2018).

## 6. Formulation of biodiesel policy recommendation

### 6.1. The Energy Act and Policy (2004) provide a framework for *Jatropha* development

The Ministry of Energy in 2006 developed a work plan with a budget of Ksh.s 40 million proposing activities for mainstreaming the processes for the establishment of the biodiesel industry. The draft proposal sets a target under which biodiesel would account for 5% of all diesel fuel by 2022. The momentum to improve the draft seems to have slackened as a result of communication and synergies among different actors and stakeholders (MoE, 2016). The enactment of the Energy Act and policy provides a framework for formulating a biofuel strategy and action plan. In early 2007, the Ministry of Energy and the parastatal under it prepared an inclusive Ksh.s. 50 million 10-year Kenya Energy Sector Environment Program (KEEP) which centered on energy and environment conservation, fuelwood, watershed management, training and publicity and awareness creation (MoE, 2016).

The Energy Act of 2006 mandates that the government pursues and facilitates the production of biofuel but does not articulate how this shall be accomplished. Liquid biofuels are only accorded a little attention in the Act, although it does at least distinguish between bioethanol and biodiesel. The Ministry of Energy, however, drafted a policy paper on biofuel in 2004 and through its National Biofuels Committee, recently produced a biodiesel strategy. The policy and strategy together provide an important starting point for the construction of a comprehensive regulatory framework. As the strategy acknowledges, more analysis is required to determine a precise policy on blending target, tax incentives, overall economics, production capacities and use of multiple feedstocks in addition to Jatropha. Biofuel activities fall under the provision of the Energy and may be regulated accordingly (IALtd 2016). The newly formed Energy Regulatory Commission (ERC) has given the explicit authority to regulate biofuel production and distribution, in addition to more traditional forms of energy such as electricity and petroleum products. NBC has called for the adoption of new regulations and where appropriate, the application of existing law regarding environmental impact assessment, child labor, penalties for non-compliance within the Energy Act (Lamotte, 2016). The National Biofuel Committee which is composed of government officials, stakeholders in research institutions, private sector and non-government organizations are currently deliberating on the framework of policy issues such as blending mandate, tax mandate, production and subsidies. The committee has put much emphasis on the promotion of *Jatropha curcas* oil for sustainable biodiesel production in the country, claiming benefits of energy security, climate change mitigation and rural development (KIP, 2016).

## 7. University research results

### *7.1. Biodiesel production*

The Technical University of Kenya has been involved in researching the potential for biodiesel production from waste cooking oil in Kenya. They produced biodiesel from waste cooking oil (WCO) and waste vegetable fats (WVF) from two hotels and chips restaurant. The waste cooking oil generated in their laboratories was also used after it has been recycled nine times. For determination of the viability of biodiesel production from waste cooking oil in Kenya, 12 hotels within the capital city were selected to determine the amount of oil generated every week. The biodiesel yield was 88 ± 2.0, 90 ± 2.6, 92 ± 1.3 and 72 ± 2.0% for 9x recycled oil, WCO from Hilton, WVF from Utalii and WCO from chips restaurant, respectively. Properties of biodiesel produced from the different batches of WCO were found to be markedly enhanced compared to those of the parent oil. Also, the values satisfied most standard limits according to the American Society for Testing Materials (ASTM) standards for biodiesel. On average, the major hotels in Kenya capital City discard 60 kg of oil/fat per week; hence biodiesel production from WCO/WVF presents a viable venture in Kenya. A 200-l prototype bioreactor for the production of biodiesel from WCO/WVF has been designed and installed at the Technical University of Kenya (Roux, Lamotte, and Achard 2017).

A study was conducted at the Institute of Energy and Environmental Technology (IEET), in Jomo Kenyatta University of Agriculture and Technology. The research entails the production of biodiesel from animal fats and evaluating its potential as an alternative fuel. It involved data collection from 13 meat processing plants and slaughterhouses near Nairobi City to establish the potential for animal fat production in Kenya. The results indicated that beef cattle and camel could produce 5.67 kg of animal fat while pig, sheep and goats can produce 7.8 kg and 1 kg, respectively. This would provide an approximated total of 180,498 tons of animal fat production potential in Kenya as of 2009. From the actual animal slaughter figures, a total of 21,265 tons of animal fat can be produced annually in the country. With a 70% biodiesel yield from the 100-l processor, a total of 14,886 tons of biodiesel could be produced. The biodiesel produced from lard and tallow feedstocks adhered to the required density and viscosity limits of 0.87894 g/ml; 0.87884 g/ml and 5.7379 $mm^2/s$ and 5.7479 $mm^2/s$ respectively. Observations for flash point and ash content were 59°C, 60°C, and 0.007% and 0.009%, respectively. The water content of 0.001% and pour point of less than 0°C for both lard and tallow biodiesels were observed. Contents of sediments were undetectable for both lard and tallow biodiesels. Engine test results showed that at 100% load, the specific rate of fuel consumption (SFC) for B100 Lard and B100 tallow were 119.79% and 124.43%, respectively as compared to fossil diesel while at 25% load, the rates reduced to 1.64% and 1.22% respectively. For the B10 blends, the specific rate of fuel consumption figures was lower than fossil diesel at 4.82% and 7.29% for B10 Lard and B10 Tallow, respectively at 100% load. At 25% engine load, the consumption for B10 lard was 0.60% above fossil diesel, while that of B10 tallow was 6.81% lower than fossil diesel (Roux, Lamotte, and Achard 2017).

### *7.2. Biodiesel testing in engines*

A research was carried out at the Department of Mechanical and Production Engineering, Moi University, Eldoret, Kenya by Munyao (2016) in which oil was extracted from *Jatropha curcas* seeds. In the study, a two-step acid-base catalytic transesterification process was used to produce biodiesel because of the number of fatty acids present in the oil. The test rig used in the experiment was an Audi 1.9 l, turbocharged direct injection, compression ignition engine. Emission was using a Horiba emission analyzer system. At the same time, combustion data was collected by the data acquisition system from which cylinder pressure and rate of heat release of the test engine in every crank angle were calculated. The two biodiesels showed better emission characteristics than the fossil diesel included in the tests for comparison purposes. Cylinder pressure and heat release of the biodiesel were also within acceptable ranges. However, the emission and combustion characteristics differed between the two biodiesels – a result likely related to their different origins. These findings prove that the source of biodiesel is an important factor to consider.

Based on collated studies with the similar results as in the aforementioned discussions, Jatropha has a lower emission of CO, HC, $NO_x$ and smoke opacity in comparison to that of diesel. Upon evaluation, a rise in CO and HC emission as result of higher engine biodiesel load with exhaust gas recirculation (EGR) gradually reduced which possibly could be because of higher biodiesel amount in the fuel blends. CO decreased from 12.32% to 6.51% and HC reduced from 27.53% to 14.91%. Emission of $NO_x$ however, increased from almost 3.29% to 10.75% within some particular conditions (Takase et al. 2015).

## 8. Commercial research results

Brief descriptions regarding commercial plans for biodiesel production in Kenya has already been reported in the previous sections. As mentioned earlier, mainly Energy Regulatory Commission and National Biofuel Committee are mandated to regulate and to allow the commercialization of biodiesel distribution throughout the country. The main focus appears to be mainly revolving around Jatropha biodiesel fuel as other indigenous vegetable oils have yet to show much economic promise in Kenya. The bodies above are involved in regulating and promoting energy production and sustainability in Kenya (Republic of Kenya Ministry of Energy and Petroleum 2016) & (IALtd 2016). Small-scale batch production units that are necessary for the production of biodiesel for a laboratory test and standardization of production and extraction process could consider:

- Engine performance test using biodiesel.
- They are involved in initiating laboratory, durability and pilot production test in various research institutions.
- Pilot generation of electricity for communities outside the main grid using biofuel as a tool to alleviate poverty.
- Promotion of private sector partnership to encourage high production of Jatropha oil to meet future demand for transport-based uses.

## 9. The possibility of harnessing indigenous algae for biodiesel production

Three major components can be extracted from microalgae biomass thus: lipids, carbohydrates and proteins. These components can be converted into many kinds of fuel including biodiesel. The lipids (which are the keys in biofuel products) have high-energy content, chemical components such as hydrocarbon molecules and triacylglycerides (TAGs) (Lamotte & Achard 2016 & Mukabane et al. 2018).

At the beginning of 2009, production of biofuels from microalgae was still in the early stages. The price of a gallon of oil from microalgae was about 21 USD. However, the cost began decreasing significantly from 6 USD to 3 USD for a gallon in 2014 and are expected to decrease to less than one dollar in the period between 2018 and 2025 (Laurens, Chen-Glasser, and McMillan 2017).

Many experiments on production of biofuels from Microalgae in some developing countries have been done including some African countries. The results were promising and thriving in the potential for good productivity of biofuels. Nile Basin countries possess a great potential for microalgae biofuel production. Countries like Kenya have a lot of features especially, emission of $CO_2$ from the cement factories and oil refineries, appropriate temperatures and vast unused lands. Moreover, these countries are developing countries and in the greatest need of energy resources to build their economies (Roux, Lamotte, and Achard 2017, & Mukabane et al. 2018).

The study carried out by researchers from Jomo Kenyatta University of Agriculture and Technology on Microalgae cultivation system for biodiesel production identify it to be economically viable. The biodiesel produced from microalgae has potential for production without the serious competition of the arable land against food and feed production. However, the prime challenge of advanced biodiesel production was its high cost. The present microalgae production and the separation of the microalgal biomass from the growing media are too costly. An estimated cost to produce a kilogram of microalgal biomass with a mean oil content of 30% is 2.95 USD and 3.80 USD for photobioreactors and open ponds respectively, assuming that carbon dioxide is available and free (Mukabane et al. 2018 & Abbas 2015).

More research and development are needed to reduce the costs of growing microalgae and separation of microalgal biomass from the growth media and to control culture contamination when grown in open ponds competently. Research and development efforts probably need to focus on the following areas: Selection and development of high yield, oil-rich microalgae: Oil-rich microalgal species which can be enhanced through cultivation and genetic engineering to increase the oil content in their biomass without compromising the biomass production rate (Mukabane et al. 2018 & Moejes and Moejes 2017).

## 10. Possibility of re-using waste vegetable oil and animal fat for biodiesel

The used domestic waste oils and spent animal fats are arguably safe and cost-effective source of useable fuel (Onuh and Inambao 2016a). Their conversion offers the merits of greenhouse gas emission (GHG), potentials for enhancing fuel diversification and qualitatively comparable energy to fossil diesel fuels. The average suspended particulate matter in Kenya is about 69.983 to 397.903 $\mu g/m^3$. This is higher than the WHO guidelines of 25 $\mu g/m^3$ and the exploitation of waste oils for biodiesel production would benefit the nation considerably (Ministry of Energy and Petroleum, & Sustainable Energy for All 2016; Mokveld and Eije 2018) .

The high cost of vegetable oils which could be up to 75% of the total biodiesel manufacturing cost has led to the production costs of biodiesel becoming approximately 1.5 times higher than that for diesel. The use of waste cooking oil (WCO) and waste vegetable fats (WVF) could greatly reduce the biodiesel cost as these are considerably cheaper than virgin oils. It would also reduce waste treatment costs associated with WCO/WVF disposal in addition to alleviating health problems related to its use (Giwa and Umanah 2019 & Awogbemi, Inambao, and Onuh 2018). For example, Ramos et al. (2019) indicated that animal fat (waste such as tallow, lard, poultry fat and fish oil) obtained during meat processing in industries serve as low-cost material for biodiesel production.

## 11. Conclusion

From the reviewed articles, it was noted that energy requirement in Kenya can be achieved and the looming energy crisis averted. However, to attain this, coherent biodiesel policies by the Government of Kenya need to be enforced with greater focus devoted to supporting the initial local research efforts. Also, NBC and ERC initiatives to engage various universities throughout the nation should be harnessed so that effective solutions can be found in meeting the requirement of the blending of biodiesel with mineral diesel by the year 2030. This is because major Kenyan research institutions and universities have reported that the biodiesel produced has met the American Society for Testing Materials (ASTM) standards.

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The authors declare that there are no conflicts of interest.

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