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Potential biofuel feedstocks and production in Zambia

Paul C. Samboko, Mitelo Subakanya, and Cliff Dlamini*

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Abstract: The need for energy security and climate change mitigation have increased blending mandates worldwide; in Southern Africa, demand for biofuels could increase following South Africa's planned blending mandates. However, land constraints limit local industry expansion, with demand likely to be met in land-abundant countries. This paper reviews the status of the biofuels industry in Zambia, as a land-abundant country, for the local and wider Southern African market. It identifies potential biofuel feedstocks as crucial elements for establishing a viable industry. Identified potential bioethanol feedstocks include sugarcane, cassava, sweet sorghum, and maize; for biodiesel, soya beans, sunflower, and groundnuts are the likely feedstocks of choice. However, current production levels are inadequate to meet growing regional biofuels demand, but there is scope for expansion if productivity and production can be increased. Presently, there is no commercial biofuel production, but a fairly adequate policy, regulatory, legal, and institutional framework exists.

Keywords: biofuels, feedstocks, Zambia, Southern Africa
JEL classification: Q16, Q18, Q12, O13

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* All authors: Indaba Agricultural Policy Research Institute (IAPRI), Lusaka, Zambia; corresponding author: sambokopc@gmail.com.

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Information and requests: publications@wider.unu.edu

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Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

Growing concerns about future energy security and global warming have necessitated investments in biofuels—a key renewable energy source that can help to mitigate global warming and contribute to future energy security and economic growth. Biofuels are also key for fostering rural development through generation of farm and non-farm income opportunities in rural areas, particularly for a growing youth population (AETS 2013; IRENA 2013). Over the last decade, global production of biodiesel and bioethanol (the two main liquid biofuels) has rapidly increased to 127.7 billion litres, with future production also expected to increase (REN21 2015). The key drivers of this growth have been: (1) the rise in the number of countries worldwide enforcing blending mandates; (2) high oil prices in 2007–08; and (3) incentives and assent to international protocols on global warming mitigation, and availability of climate finance for renewable energy development (IRENA 2013; Locke and Henley 2013; REN21 2015).

The blending mandates in the European Union (EU) and United States of America (USA), and the availability of climate financing following the enforcement of the Kyoto Protocol in 2005, triggered large biofuels investments in Southern Africa. Many multinational companies invested in developing countries such as Zambia, Mozambique, Malawi, and South Africa. They often acquired and underutilized large pieces of land for biofuels production (Locke and Henley 2013). However, by 2012 most of them had down-scaled, suspended, or terminated operations. The reasons advanced for this poor performance include: (1) lack of necessary policies to support production; (2) lack of feedstocks; (3) lack of financing (partly a consequence of the global financial crisis in 2008–09; and (4) poorly understood feedstocks under local conditions, often with experimentation of feedstock production models (German et al. 2011b; Locke and Henley 2013; MEWD 2016).

Biofuel investments are expected to rise in the future, especially in the land-abundant developing countries, mostly because of the rising number of countries enforcing biofuel blending mandates across the globe (REN21 (2015) report that in 2015 33 countries had blending mandates in place). In Southern Africa in 2015, there were existing mandates in Zambia, Zimbabwe, and Mozambique; in the same year, South Africa planned to enforce 5 and 10 per cent blending mandates for biodiesel and bioethanol (Wenberg 2013). Being a major petroleum consumer, this could significantly increase regional demand for liquid biofuels.

Zambia is poised to become a major contributor to the growth of the biofuels industry in the region. It has abundant land that can be used for feedstock production, with a land–person ratio of 5.79 hectares (ha), which is relatively large when compared to the industrialized world at 0.01–4.23 ha per capita (Sinkala et al. 2013). This is complemented by political stability and a climate that is conducive to a wide array of feedstocks that can be grown in tropical and subtropical regions. Its near-central location within Southern Africa offers trade opportunities for both feedstock and liquid biofuels.

However, a viable biofuels industry will depend on sustained supply of cost-effective feedstocks. More importantly, the benefits from biofuels expansion will only materialize if the appropriate policy, institutional, and legislative framework is in place, and implemented in a way that ensures benefits accrue to the country and other players in the value chain. This is important, given the reasons alluded to earlier for the industry's poor performance in the past.

In this paper we look at the status of the biofuels industry in Zambia. We also identify feedstocks that can be mobilized for biofuels production, their current production levels, and costs of production. An analysis of the agroecological zones (AEZs) best suited for producing these feedstocks is also provided. We discuss the scope for expanding feedstock production, and the economics of biofuels production, based on the existing literature. An evaluation of the biofuels policy and legislative framework is also conducted to best understand the gaps that need to be filled if Zambia is to benefit from a biofuels expansion.

Throughout the paper the term 'biofuels' refers to only biodiesel and bioethanol, which account for 90 per cent of biofuels produced globally. These can be produced from agricultural and forest products or the biodegradable portion of industrial and municipal waste (FAO 2008).

This paper therefore provides answers to the following key questions:

1. Which locally produced feedstocks can be used in the production of first-generation biofuels, and what are the current production levels?
2. Is there scope for expanding feedstock production?
3. Which regions are best suited to the production of identified potential feedstocks?
4. Is the current biofuel legal, policy, and regulatory framework conducive for industry growth?
5. What is the state of implementation of the biofuels policy framework?

The rest of the paper is structured as follows. Section 2 presents the research methods and describes the data sources. In Section 3, an overview of the biofuels industry is presented, focusing on the industry's evolution, lessons learned, and the status of the legal, regulatory, and policy framework. Section 4 discusses potential biofuel feedstocks, current production levels, and the associated production costs. In Section 5 we discuss the agro-climatic suitability of identified potential feedstocks. The constraints to feedstock production, and scope for expansion, are discussed in Section 6. Thereafter, we conclude the paper.

2 Data and methods

2.1 Research methods

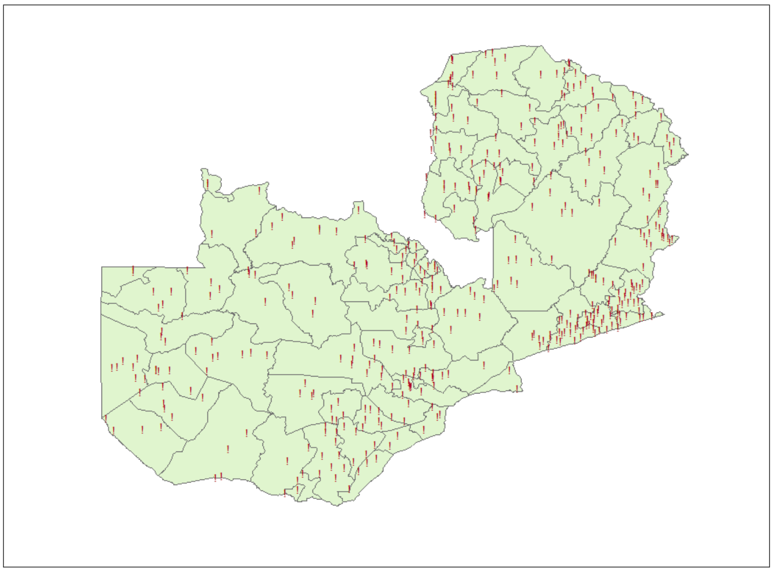
The study uses a combination of qualitative and descriptive analyses to achieve the objectives. Given a wide range of cross-cutting literature on biofuels in Zambia and elsewhere, we also reviewed relevant literature on the subject to understand developments in the biofuels industry across Southern Africa. We reviewed policy documents and interviewed staff from the Ministry of Energy and Water Development (MEWD), and the Biofuels Association of Zambia (BAZ). The descriptive analysis utilized two nationally representative surveys, namely the annual Crop Forecast Survey (CFS), and the 2015 Rural Agricultural Livelihoods Survey (RALS). To understand the feedstock production costs, enterprise budgets from the Zambia National Farmers Union (ZNFU) were used. Consumption data on petrol and diesel were sourced from Zambia's Energy Regulation Board (ERB).

2.2 Description of survey data

The annual CFSs are collected by the Ministry of Agriculture (MoA) in collaboration with the Central Statistical Office (CSO), with support from the Indaba Agricultural Policy Research Institute (IAPRI). It is nationally representative and covers all farmer categories (i.e. small- and large-scale farmers).

The RALS is a panel survey on rural livelihoods that is collected every three years. For this paper we use the 2015 RALS survey data, which cover 476 standard enumeration areas (SEAs) across ten provinces (Figure 1). A total of 7,934 households is used for the analysis; in total 8,840 households were interviewed. For detailed information on RALS coverage and sampling, the reader is referred to Chapoto and Zulu-Mbata (2015a).

Figure 1: Distribution of SEAs in RALS 2015.



Source: Chapoto and Zulu-Mbata 2015a, reproduced with permission.

3 Overview of the biofuels industry in Zambia

3.1 Industry evolution

The early firms

The global biofuels boom in the early 2000s led to major investments in Zambia by firms such as Kaidi Biomass Development Plc, D1 Oils, Oval Biofuels, and Marli Investments. Commercial biofuels production in Zambia started in the early 2000s with six major firms engaging in production (D1 Oils, ETC Bioenergy, Marli Investments, Oval Biofuels, Kansanshi Mines, and Southern Biopower) (Chu 2013). The majority of the early firms engaged in biodiesel production using *Jatropha*, while experimenting with production models (German et al., 2011b).

Around 2006 there was increased government interest in the industry's development, and this led to the development of a policy, institutional, and legislative framework to help develop the industry. A biofuels association was also set up in 2006 to support this process, and presently has 28 active members. However, despite this progress, by 2012 most of the early firms had ceased operations or down-scaled their projects, while other firms such as Southern Biopower ventured into biogas-based waste management. The large amounts of land acquired by these firms remained largely unutilized, with less than 1 per cent used for the planned investments in biofuels and feedstock production (Locke and Henley 2013). The key events in the industry's evolution are summarized in Table 1.

Table 1: Key dates in the development of Zambia's biofuels industry

Activity	Year
Biofuels association set up	2006
Commercial production commences	2006
Biofuels included in National Energy Policy (NEP)	2007–08
Biofuels Standards developed (ZS E100 and ZS B100 for bioethanol and biodiesel respectively)	2006–07
Draft guidelines given for storage, transportation, and retailing	2008
Statutory Instrument No. 42 recognizes biofuels as part of the energy mix	2010
Blending ratios are established	2011
Tenders to supply biofuels are advertised; six firms bid and three are allocated	2014
Biofuels pricing mechanism is established	2014
There is renewed interest in large-scale commercial liquid biofuels production	2014 to present

Sources: based on ERB 2008; MEWD 2011, 2016; Sinkala 2010; Sinkala et al. 2013.

Explaining the poor performance of the industry in the past

A number of reasons have been advanced to explain the remarkable exit of many firms in the biofuels industry across Southern Africa. Most are associated with a lack of investment financing resulting from the global financial meltdown in 2008/09; the lack of an adequate policy, institutional, and legislative framework, where it existed at all; the lack of supply contracts with government as the main off-taker; and inadequate local and regional demand. The lack of feedstocks, especially for biodiesel, was also a major contributing factor. In some instances, even with the land abundance in some countries, firms were not granted the amount of land requested for investments (German et al. 2011b; MEWD 2016; Nolte et al. 2014; Sinkala et al. 2013). Below we discuss some of the key factors in the case of Zambia.

The *institutional, policy, and legislative framework*. Perhaps one of the main reasons for this phenomenon in Zambia is that the industry's growth proceeded at a faster rate than that at which the necessary policies and legislation were put in place (Chu 2013). For instance, ever since commercial production began, there have been no biofuel supply agreements between the Zambian government (as the main off-taker through Indeni Oil Refinery) and the private sector. This meant that firms could not make further production/investment decisions as there was no guaranteed market for biofuels locally, except for separate private arrangements with individuals or firms. This also meant that firms could not secure funding from financial institutions using the supply agreements as security.

Government subsidies on fuel. The failure by the early firms was also a direct consequence of government's subsidies on fossil fuel imports (Locke and Henley 2013), with subsidies rendering biofuels uncompetitive against fossil fuels. These were removed in 2013 and later in 2016 in an effort to move towards cost-reflective pricing of energy products, including biofuels, and to reduce a growing fiscal deficit. To date, the ERB has not finalized the biofuels cost-reflective prices (ERB 2014; Sinkala 2016b).

Inadequate land for large-scale investments. While other firms managed to acquire and underutilize large tracts of land allocated to them for biofuel investments, there are suggestions that inadequate land was one of the main contributing factors to the exit of Kaidi Biomass Plc. The firm was only allocated 5 per cent of the 80,000 ha of land applied for (Sinkala et al. 2013). To put this into perspective, when firms sign biofuel off-take agreements with the state, they require a feedstock guarantee from their own production, mainly because small-scale production through outgrower schemes is not always guaranteed. As such, where adequate land is not provided, firms may opt not to invest as the risks from failure to meet supply contracts may lead to legal action by the off-taker (Sinkala, 2016).

Lack of finance. The 2008–09 global recession adversely affected many firms. This affected the ability of early firms to secure international funding for biofuel investments. As a result, early firms were forced to exit the biofuels industry in Zambia (e.g. D1 Oils).

Lack of feedstocks and inadequate expertise. Most early firms wanted to produce biodiesel using *Jatropha*. However, the early firms and their outgrowers possessed inadequate knowledge of *Jatropha*, especially under local conditions. They experimented with unproven production models, often with disastrous outcomes. Consequently, they exited the industry or down-scaled operations, with most of the *Jatropha* grown left unharvested, especially in outgrower schemes. Other biodiesel feedstocks could not easily be sourced (see German et al. 2011b; Locke and Henley 2013; MEWD 2016). To date, one can still find largely unutilized *Jatropha* plants in farmer fields across Zambia.

Biofuels production and consumption demand

Presently, there is no commercial biofuels production in Zambia. Production is in small quantities, mainly for internal purposes among firms such as Thomro Biofuels and Bruno's Jatropha. Only the Copperbelt Energy Corporation (CEC) and Zambia Sugar Plc produce relatively large amounts of biofuels, and this is for internal purposes.

More recently, there have been new entrants to the Zambian biofuels industry, with major interests in bioethanol processing. These include Sunbird Bioenergy from the United Kingdom, who plan to produce 20 million litres of bioethanol annually (which represents about 41 per cent of Zambia's bioethanol requirements for 2015), and Green Fuels from Zimbabwe. Production by these firms is yet to commence, as the investments are still in the early stages. There are also plans by Thomro Biofuels to begin bioethanol production by early 2017, following a grant from a non-profit organization. We anticipate an increase in renewable energy investments as more countries enforce blending mandates and financing for such investments becomes more readily available from international sources. At the 15th Conference of the Parties in 2009, developed countries committed to a goal of mobilizing US$100 billion for climate finance by 2020, of which US$10 billion was pledged to the green climate fund by 2015 (Callaghan 2015).

Using consumption demand for diesel and petrol and the biofuel blending mandates outlined in the 2008 NEP, we estimate Zambia's demand for bioethanol and biodiesel in 2015 at 48.9 and 48.7 million litres, respectively (Table 2). This is significantly lower than demand that may come from South Africa.

Table 2: Estimated demand for biodiesel and bioethanol (million litres)

Year	Diesel consumption*	Biodiesel demand** (5 per cent blending)	Petrol consumption*	Bioethanol demand** (10 per cent blending)
2011	679.8	34.0	242.8	24.3
2012	795.0	39.8	312.3	31.2
2013	795.4	39.8	367.5	36.7
2014	834.0	41.7	406.1	40.6
2015	974.3	48.7	488.7	48.9

Sources: * based on ERB 2014; ** authors' calculations.

3.2 State of the policy, institutional and legislative framework

One of the key ingredients to a successful biofuels industry is a comprehensive policy, institutional, and legislative framework that is effectively implemented. In this section, we evaluate the biofuels policy, institutional, and legislative framework in Zambia and the extent to which it is implemented. Other policies relevant to the industry include the land, environmental, forest, and agriculture policies, the Constitution of Zambia, and the Revised Sixth National Development Plan (RSNDP). Land is especially important, given competing uses such as food production, mining, human settlements, and others.

The policy framework

The Zambian government views biofuels as an important industry for reducing the petroleum import bill, while contributing to energy diversification and security (GRZ 2008, 2013). Further, through its backward linkages with agriculture for crop-based feedstocks, the biofuels industry is seen to be key for promoting crop diversification and income growth, particularly among smallholder farmers. Its development is also important for non-farm opportunities, as biofuel processing firms are likely to locate in rural areas, where wages are low (e.g. see Foster and Rosenzweig 2003). Since commercial biofuel production commenced around 2006, progress was made towards developing a biofuels policy, institutional, and legislative framework. The NEP of 1994 was revised to accommodate biofuels, and to promote private sector participation in the energy sector and biofuels are now objectives of the 2008 NEP. Policy measures covered in the NEP include trade, production, and blending of biofuels. It also highlights industry regulation, the legal and institutional framework, data availability on biofuels, and investment support through incentives and research as key policy measures required for the development of the industry.

To support production, in 2009 blending ratios for bioethanol and biodiesel were set at 10 per cent and 5 per cent, respectively. This implies that there is no need for modification of existing petrol and diesel vehicle engines, and there is no need for special vessels to transport blended petrol and diesel (MEWD 2011). Within the NEP, up-scaling biogas technologies for cooking, lighting, and electricity generation is one policy measure for diversifying the energy mix in light of rapidly growing demand for energy (GRZ 2008, 2011). Additionally, to support local trade in produced liquid biofuels, Zambia drafted a pricing mechanism for liquid biofuels in 2014. This was determined by applying a 0–5 per cent discounted rate to the wholesale price of diesel and petrol.

This implied that in 2014, at wholesale prices of ZMW5.47 and ZMW6.20 for diesel and petrol, respectively, corresponding bioethanol and biodiesel prices before tax/subsidies would be ZMW5.20 and 5.89 per litre, respectively (*Times of Zambia* 2014). However, there are proposals to revise the pricing mechanism because it is stated in Zambian kwacha, making it susceptible to the kwacha's volatility against the US dollar. The motive behind this is that having the pricing mechanism in kwacha may reduce the ability of firms to pay back investment loans issued in foreign currencies or from international tenders (Sinkala 2016a).

Biofuels standards were also issued by the Energy Regulation Board in 2008 (i.e. ZS E100 for bioethanol and ZS B100 for biodiesel). This allowed firms to trade in unblended biofuels directly with customers, without having to supply the government-owned oil refinery for blending (MEWD 2011).

Because the production of first-generation biofuels is likely to be impacted by policies in the agricultural sector, we also look at agricultural policies and how these may impact on crop-based feedstock availability. Agriculture in Zambia contributes 8.1 per cent to gross domestic product (GDP) (Kuteya 2016) and, as in other developing countries, its growth is seen to be the clearest avenue for reducing poverty (Pinstrup-Andersen and Pandya-Lorch 1995). Generally, Zambia's agricultural policy is very favourable, with a crop diversification agenda in full effect, and the biofuels industry stands to benefit from the country's emphasis on agricultural development.

Currently, Zambia is reviewing its land policy, with an updated document still in draft form pending further consultations with key stakeholders. This is expected to be finalized by the end of 2017. While individuals and firms can acquire land through traditional leaders and the state for investment purposes, compared to customary land the acquisition of state land is often characterized by complex procedures and bureaucracies (German et al. 2011a). The new land policy is expected to strengthen the security of tenure, and thus promote sustainable land use. It is also expected to embrace gender equality on land issues, thus ensuring equal access to land by both male and female citizens. The land question will be addressed in detail in a forthcoming paper.

While sustainable production of biofuels is mentioned in the NEP, other sectoral policies are also important, considering the likely impact of biofuels production on the environment. These include the National Policy for the Environment and the National Forestry Policy (GRZ 2009). These two policies are meant to promote sustainability in the development and utilization of natural resources. For all investors in the biofuels industry, the Zambia Development Agency (ZDA) demands a mandatory Environmental Impact Assessment (EIA) report from the Zambia Environmental Management Agency. Whether these achieve their intended goals in practice is not addressed in this paper.

The institutional and legislative framework

The purpose of the legal framework for the energy sector in general and biofuels industry in particular is to promote effective and sustainable exploitation of energy resources (GRZ 2008). The supreme law that governs all legal matters is the Constitution of Zambia. There are, however, specific pieces of legislation that govern the biofuels industry, such as Statutory Instrument No. 42 of 2008, which recognizes biofuels as part of the energy mix (MEWD 2011). Further, ZDA Act No. 11 of 2006 is the main piece of legislation directly related to biofuels investments. GRZ (2008) lists other Acts of parliament relevant to the energy sector as a whole, including the:

- Petroleum Act;
- Electricity Act;
- Energy Regulation Act;
- Rural Electrification Act;
- Environmental Protection and Pollution Control Act;
- Zambezi River Authority Act;
- Local Government Act;

- Forestry Act;
- Land Act; and
- Mines and Minerals Act.

Biofuel investment incentives

To promote the growth of the biofuels industry, biofuels are listed among the priority investments under Energy and Water Development in ZDA Act No. 11 of 2006. This Act lists a number of fiscal and non-fiscal incentives aimed at promoting investments in the energy sector (Table 3). Investments considered here are for building and installation of processing and refinery plants for biofuels, constructing petroleum refineries and oil pipelines, and rural filling stations (ZDA 2015).

Table 3: Incentives and qualifying thresholds under ZDA Act No. 11 of 2006

Investment threshold	Incentives
≥US$500,000	*1 Fiscal incentives* • Zero per cent tax rate on dividends for five years from year 1. • Zero per cent tax on profits for five years from the first year of operation (if project is in a rural area or multi-facility economic zone (MFEZ)). • Zero per cent import duty rate on capital goods and machinery, including specialized motor vehicles. *2 Non-fiscal incentives* • Investment guarantees and protection against state nationalization. • Free facilitation for application of immigration permits, secondary licences, land acquisition, and utilities.
≥US$250,000	*1 Non-fiscal incentives* • Investment guarantees and protection against state nationalization. • Free facilitation for application of immigration permits, secondary licences, land acquisition, and utilities.

Source: based on ZDA 2015.

3.3 Status of implementation of the biofuels policy and legislative framework

Despite Zambia having a policy and legislative framework that sets the stage for sustained growth in commercial biofuel production, more needs to be done to ensure this becomes a reality. To date, no supply tenders or off-take agreements are in place between the government (as the sole off-taker) and independent biofuel suppliers, and this is holding back potential investments. Tenders to supply biofuels to the government were allocated to three firms in 2014, and later cancelled because of infighting within government, and because of the change in ministers and the associated shift in priorities. To date, no progress has been made towards finalizing these (Sinkala 2016a).

Experience with the early firms shows that despite the policy framework highlighting the need for a legislative and institutional framework that will protect firms and individuals alike, there is limited capacity to hold investors accountable for any adverse environmental and social factors. This was true especially for the early firms that engaged *Jatropha* outgrowers, who left these outgrowers without a market when exiting the industry (see German and Schoneveld 2012). Understandably, this happened at a time when private sector activity in the industry far exceeded the government's efforts to put in place and implement the policy and legal framework to protect smallholders and firms (see German et al. 2011b).

Additionally, despite mention of implementation of the blending mandates in the RSNDP (2013–16), and the 2008 NEP, this is yet to be done. And because blending is yet to commence, the pricing mechanism is yet to be implemented, let alone revised. One reason why blending has not yet started is that an assessment of the cost of setting up such infrastructure is yet to be done. The plan is to set up blending infrastructure at several depots across the country instead of just at Indeni Oil Refinery in Ndola. Another reason is that there is not adequate commercial liquid biofuels and feedstock production to satisfy local demand (MEWD 2016; Sinkala 2016a; ZDA 2014).

In terms of research to support biofuels production, the University of Zambia's Plant Sciences Department ranks biofuels research as second in their research priorities. Since 2007, extensive research has been conducted with other partners to develop sweet sorghum as a bioethanol feedstock (see Box 1). There are no records of other government research in the industry to, for example, understand the economics of setting up blending infrastructure. With the Farmer Input Support Programme (FISP) and price support via the Food Reserve Agency (FRA) consistently taking up a large share of the agricultural budget (98 per cent in 2016) (see Kuteya 2015, 2016), it remains to be seen how public agricultural research for biofuels production will be achieved with limited public funding.

With respect to investment support through incentives, the policy framework through ZDA Act No. 11 of 2006 supports industry growth. However, it is likely that very few firms—if any—have fully benefited from these investments, given that most of them exited the industry shortly after entering.

In terms of its role in ensuring availability of data on resource assessment, it is safe to say that this is usually available through various government ministries. For example, feedstock availability data can be sourced from the Central Statistical Office (CSO) and Ministry of Agriculture. Fuel consumption demand data are readily available from the Energy Regulation Board (ERB).

With respect to sustainable production of biofuels, EIAs are mandatory among investors; as such, implementation of this aspect of the policy is almost guaranteed. However, practice is likely to diverge, with probable negative social and environmental outcomes.

4 Potential biofuel feedstocks and production

At present, biofuels produced worldwide are first-generation. Higher-generation biofuel technologies are still in the developmental stage; as such, our discussion focuses on first-generation biofuel feedstocks.

Among the crop-based feedstocks, those containing oil (e.g., soya beans, sunflower, rapeseed, groundnuts) are used to produce biodiesel, while carbohydrate-containing feedstocks (e.g., wheat, maize, sweet sorghum, barley, rice, rye, sugarcane) are used in bioethanol production. The choice of feedstocks used in biofuel production depends on the availability and cost effectiveness of the feedstocks. In the EU and USA, bioethanol is mostly produced using wheat and corn, respectively. Biodiesel is mainly produced from rapeseed in the EU and soya beans in the USA.

There are many feedstocks that have been identified as potentially suitable for Zambia. For biodiesel, suitable and locally grown crops include *Moringa*, *Jatropha*, soya beans, sunflower, castor, seed cotton, cashew nut, groundnuts, and oil palm. For bioethanol, locally grown feedstocks include sugarcane, agave, sweet sorghum, maize, cassava, pineapples, and sweet potatoes (see

Sinkala et al. 2013). Wheat, Irish potatoes, tropical sugar beet, and seed tobacco are crops grown in Zambia that can also potentially be used as feedstocks. Tobacco can be used to produce biofuels if it is left to overgrow, producing seeds (in this paper we use the terms tobacco and seed tobacco interchangeably). While there is no list of approved or preferred feedstocks, the MEWD has promoted sugarcane and *Jatropha* (MEWD 2016).

To date, firms in Zambia have produced biodiesel using *Jatropha*, *Moringa*, and soya beans, while bioethanol has been produced from sugarcane by-products (e.g. molasses by Zambia Sugar Plc) (ZDA 2014), and, more recently, cassava has become a preferred feedstock. But biodiesel production using *Jatropha* proved challenging, given the lack of feedstock, as many firms experimented with the feedstock under different production models. More recently, firms have been using cassava (e.g. Sunbird Holdings) and soya beans (e.g. Copperbelt Energy Corporation) for bioethanol and biodiesel production, respectively.

4.1 Trends in feedstock production levels and yields

Bioethanol feedstocks

Table 4 shows the trends in the production of potential biofuel feedstocks in Zambia. While production of some feedstocks has increased over the last five years, other feedstocks show sharp declines in production levels. This is particularly the case for sorghum and many of the biodiesel feedstocks.

Table 4: Trends in the production of biofuel feedstocks (2010–15) (metric tonnes)

Crop	2010	2011	2012	2013	2014	2015
Cassava	–	3,020,380	4,425,168	4,458,333	3,677,987	3,811,387
Soya beans	111,888	116,539	203,038	261,063	214,179	226,323
Sunflower	26,420.4	21,954	20,468	33,733	34,264	34,726
Sugarcane	3,500,000	3,500,000	3,900,000	4,000,000	–	–
Sorghum	27,732	18,458	15,379	14,971	11,557	8,123
Groundnuts	164,602	139,387.6	113,026	106,792	143,591	111,429
Maize	2,795,483	2,786,896	2,852,687	2,532,800	3,350,671	2,618,221
Irish potatoes	22,940	27,563	32,066	22,038	33,833	45,902
Seed cotton	72,482	121,908	269,502	139,583	120,314	103,889
Virginia tobacco	22,074	27,145.6	24,250	21,195	26,105	19,811
Burley tobacco	9,809	11,141.0	7,067	8,704	9,564	6,083
Sweet potatoes	252,867	146,614	163,484	188,355	150,158	118,330
Pineapples	–	105	4,689	7,751	–	14,163

Sources: Ministry of Agriculture Crop Forecast Surveys (2010–15); and FAOSTAT (for sugarcane).

Among the crops that can be used to produce bioethanol, the highest production levels are for sugarcane,[1] followed by cassava and maize, at 4, 3.8, and 2.6 million metric tonnes, respectively. Production is lowest for sorghum at 8,123 metric tonnes, with a sharp decline in production (56 per cent) over the last five years. This is followed by pineapples, Irish potatoes, and sweet potatoes at 14,163, 45,902, and 118,330 metric tonnes, respectively.

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[1] Sugarcane production statistics are for 2013. However, production is expected to increase with expansion by Zambia Sugar Plc, which is the major sugar producer. Sixty per cent of sugarcane is produced by the three main processors: Zambia Sugar (Illovo), Kafue Sugar, and Kalungwishi Estates (Chisanga et al. 2014).

There are no survey data on agave and *Moringa* to help us determine current production levels. However, agave is usually grown in small quantities as an ornamental or fencing crop in hedges (Sinkala et al. 2013). There are some firms growing *Moringa*, such as Thomro Biofuels.

Biodiesel feedstocks

For the feedstocks that can be used in biodiesel production, output is highest for soya beans and groundnuts at 214,179 metric tonnes and 143,591 metric tonnes, respectively. The production of tobacco is the lowest at 9,811 and 6,083 metric tonnes for Virginia and burley, respectively. Sunflower is also produced in very small quantities (i.e. 34,264 metric tonnes). There is some oil palm production under large-scale investments in Northern Zambia, by ZamPalm (2,800 ha). There have also been traces of smallholder oil palm production in the Mwense District (Luapula Province) by Isubilo Oil Palm Cooperative, which is reported to have 120 farmers producing 35 ha of oil palm (*Lusaka Times* 2015; *Times of Zambia* 2015). However, this is mainly for cooking oil production. There are no production data on *Jatropha*, cashew nuts, or castor. When the early firms entered, land under *Jatropha* was estimated at 6,000 ha (see ZDA 2014); there is no record of how much land remains under *Jatropha*. But it seems plausible that some of the trees, if not cleared, still remain to date. Other *Jatropha* trees may be found as fencing around rural homesteads. In fact, a visit to Luapula and Northern Provinces in April 2016 revealed that some households (especially in Northern Zambia) still have *Jatropha* plants over many hectares. One farmer stated: 'I grew Jatropha when it was being promoted by Stichting Nederlandse Vrijwilligers (SNV) Zambia, and I have 2 hectares under Jatropha, but our only challenge is finding a market.' We found that in the same area, farmers still have *Jatropha* seed stored at their homesteads.

Feedstock yields

Table 5 shows crop yields for smallholder and large-scale farmers in 2015. It also shows the yields of the highest yielding smallholder farmer, which is computed as the average yield in the upper quintile for each crop. Clearly, smallholder farmer yields are significantly lower than those of large-scale farmers.

Table 5: Average yields for selected feedstocks (metric tonnes per hectare)

Crop	(1)* Large-scale	(2) Smallholder	(3) High-yielding smallholder farmers
Maize	4.36	2.13	4.81
Sorghum	0.96	0.68	1.53
Irish potatoes	24.98	6.40	5.83
Pineapples	–	12.06*	–
Sweet potatoes	3.87	4.27	8.64
Soya beans	2.67	0.85	1.67
Sunflower	1.02	0.57	1.20
Seed cotton	0.74	0.98	2.12
Virginia tobacco	2.37	1.51	2.07
Burley tobacco	1.35	1.35	1.96
Groundnuts	1.28	0.67	1.63
Cassava	–	5.87	13.79

Sources: based on 2015 RALS; 2015 Crop Forecast Survey for (1).

Under smallholder production, yields for biodiesel feedstocks are lowest for sunflower at 0.57 tonnes per hectare. This is against a potential of 1.2 tonnes per hectare. Soya beans and groundnuts yields are also very low at 0.85 and 0.67 metric tonnes per hectare, respectively. Yields are highest for Virginia tobacco at 1.51 tonnes per hectare, followed by burley tobacco and seed cotton at 1.35 and 0.98 tonnes per hectare, respectively. Under commercial production, yields are lowest for seed cotton, followed by sunflower, groundnuts, and burley tobacco. Yields are highest for soya beans, at 2.67 tonnes per hectare, followed by Virginia tobacco at 2.37 tonnes per hectare.

For bioethanol feedstocks under smallholder production, pineapples are the highest yielding (12.1 metric tonnes per hectare), followed by Irish potatoes (6.4 tonnes per hectare) and cassava (5.9 tonnes per hectare). The lowest yields are observed for sorghum at 0.68 metric tonnes per hectare.

When we compare the average yields of smallholders against the potential yields, irrespective of crop (Table 5, column 3), the yield gap is significantly large, indicating potential for increasing production through productivity improvements.

4.2 Feedstocks offering promise based on current production

Based on the production levels in Table 4, potential bioethanol feedstocks include maize, sugarcane, and cassava. Soya beans and groundnuts are also produced in relatively large quantities, making them potential biodiesel feedstocks. Maize is unattractive as a biofuel feedstock in Zambia because it is given special attention as a staple food crop and is subject to ad hoc government policies related to trade, input subsidies, and price support. On the other hand, cassava is a staple food crop in the areas where it is mainly grown. Currently, the national food balance sheet shows about 104,008 metric tonnes of surplus cassava flour in the 2015/16 marketing season. While this can be used for bioethanol production, it is not sufficiently large.

Irrespective of the current production levels, sweet sorghum and sugarcane offer more promise as bioethanol feedstocks, especially because sweet sorghum can be used as a dual-purpose crop for bioethanol and food production. Sugarcane is attractive because bioethanol can be produced using sugar molasses (a sugar by-product), making it a long-term candidate in light of the food versus fuel debate that comes with biofuels expansion. Extensive research on sweet sorghum in Zambia and the results so far show very good potential in its use as a bioethanol feedstock, especially for small-scale processors (Box 1).

Box 1: The promise of sweet sorghum as a bioethanol feedstock in Zambia

Since 2004, the University of Zambia's School of Agricultural Sciences has collaborated with a number of international and local institutions to carry out extensive research aimed at developing sweet sorghum varieties best suited for bioethanol production in Zambia. This was done in light of the fact that it can be grown twice in an agricultural year, given its short maturity period, and because it is a dual-purpose crop. It is also advantageous over sugarcane due to its low input requirements and high water-use efficiency, making it suitable for most parts of the country.

The research focused on (1) an evaluation of the performance of exotic sorghum varieties in three AEZs; (2) development of improved genotypes for bioenergy production (i.e. with high biomass and sugar content); (3) identification of molecular markers for sugar content in sweet sorghum to ease identification of choice feedstocks in the field; and (4) economic evaluation of sweet sorghum in bioethanol production.

Findings from the research highlight that the productivity of the exotic varieties was generally very low under local conditions. However, when crossed with Lusitu (a local variety), the resulting varieties yielded many desirable traits for bioethanol production.

Exotic varieties best suited for bioethanol production are Wray, Proj1, and TS1. Under optimal fertilizer application, with supplemental irrigation before the onset of the rains, Wray, GE3, and Cowley yield 70.2, 82.5, and 71.5 tonnes per hectare, respectively, with sugar content of 20.4, 18.5, and 13.8 per cent, respectively. This translates to 3,575, 3,926, and 3,167 litres of bioethanol per hectare of Wray, Proj1, and TS1, respectively. When harvested twice, this increases to 7,316 for Wray, 6,439 for GE3, and 4,178 for Cowley. These yields are significantly large when compared to the 1,530 kg per hectare that is received by the highest yielding farmers at present (see Table 5, column 3). More recently, stem yields for sweet sorghum varieties on trial average 100 metric tonnes per hectare, which is significantly higher than local varieties such as SIMA, which yield 30–40 metric tonnes per hectare.

AEZ II (see Figure 2) was identified as the most appropriate for sweet sorghum under a high input management system, yielding 46 per cent more ethanol than other regions under the same management conditions. When produced under low input management system in AEZ II, yields were 27 per cent lower. This offers promise in production under smallholder farming with low input-use intensity. Following this work, there is potential for further development of sweet sorghum to make it more resilient to biotic and abiotic stress.

Sources: Munyinda 2016; Munyinda et al. 2014.

4.3 Feedstock production costs and the economics of biofuels production

Feedstock production costs

Table 6 shows the production costs of various feedstocks that can be used in biofuel production. Among the potential bioethanol feedstocks under smallholder production, production costs are highest for maize at ZMW5,664 per hectare, while sorghum production costs are ZMW3,434 per hectare. When commercial production is considered, it costs over twice as much to produce one hectare of maize under rain-fed conditions. Commercial Irish potato production costs are ZMW94,947 per hectare under irrigation. Data for the remaining feedstocks are unavailable. Among the biodiesel feedstocks that can be produced, it costs smallholders ZMW5,703 to produce one hectare of sunflower, which is 31 per cent more than it costs to produce soya beans and 33 per cent more than it costs to produce groundnuts under the same conditions.

Table 6: Comparing the costs of feedstock production

Crop	Smallholder, rain-fed	Commercial		
		Rain-fed	Irrigated	Supplementary
Total production costs (ZMW per hectare)				
Maize	5,664	12,469	–	–
Sorghum*	3,434	–	–	–
Irish potatoes	–	–	94,947	–
Sunflower*	5,703	10,199	–	–
Soya beans	7,479	–	–	11,798
Seed cotton	–	–	–	–
Tobacco	–	–	–	43,868
Groundnuts	7,613	–	14,236	–
Total variable costs (ZMW per hectare)				
Maize	3,631	7,993	–	–
Sorghum*	2,525	–	–	–
Irish potatoes	–	–	58,429	–
Sunflower*	3,656	6,538	–	–
Soya beans	4,794	–	–	7,563
Seed cotton	2,053	–	–	–
Tobacco	–	–	–	28,121
Groundnuts	4,880	–	8,761	–
Gross margin				
Maize	–1,007	459	–	–
Sorghum*	582	–	–	–
Irish potatoes	–	–	39,464	–
Sunflower*	–2,757	4,585	–	–
Soya beans	53	–	–	899
Seed cotton	803	–	–	–
Tobacco	–	–	–	10,655
Groundnuts	3,806	–	13,049	

* Smallholder estimate is for production under conservation agriculture.

Source: based on ZNFU 2015.

Under commercial production, it costs ZMW14,263 per hectare to produce irrigated groundnuts, while soya beans costs ZMW11,798 with supplementary irrigation. Commercial tobacco costs ZMW43,868 per hectare with supplementary irrigation.

4.4 Costs of biofuels production

In perhaps the only effort so far to understand the competitiveness of biofuels against their petroleum counterparts in Zambia, Sinkala et al. (2013) determine the costs of biofuels production using different feedstocks. Their results show that for bioethanol, cassava is the most cost-effective feedstock, followed by sugarcane and sweet sorghum, while agave is the least cost-effective feedstock. For biodiesel production, the most cost-effective feedstock is oil palm. It costs almost the same amount to produce one litre of biodiesel using soya beans as it does using *Jatropha* (i.e. US$0.6). Groundnuts and castor cost about US$0.7 per litre. Sunflower, on the other hand, is the least cost-effective feedstock (Table 7).

Table 7: Comparing biofuel production costs using different feedstocks (production cost in US$ per litre)

		Without CDM credits[a]		With CDM credits	
		10 per cent interest rate	16 per cent[b] interest rate	10 per cent interest rate	16 per cent interest rate
Bioethanol	Sugarcane	0.521	0.542	0.453	0.473
	Sweet sorghum	0.524	0.545	0.434	0.455
	Cassava	0.353	0.36	0.301	0.309
	Agave	0.652	0.68	0.594	0.622
Biodiesel	Soya beans	0.635	0.655		
	Oil palm	0.594	0.612		
	Jatropha	0.669	0.677		
	Groundnuts	0.741	0.761		
	Castor	0.772	0.792		
	Sunflower	0.918	0.952		

[a] CDM stands for Clean Development Mechanism, a mechanism designed under the Kyoto Protocol to help signatories earn saleable credits that can count towards meeting the Kyoto Protocol targets (http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php).

[b] Note that 16 per cent was the cost of finance in Zambia in November, 2011; 10 per cent is a hypothetical cost of borrowing that the authors assume if competition were to increase in Zambia's financial sector.

Source: based on Sinkala et al. 2013.

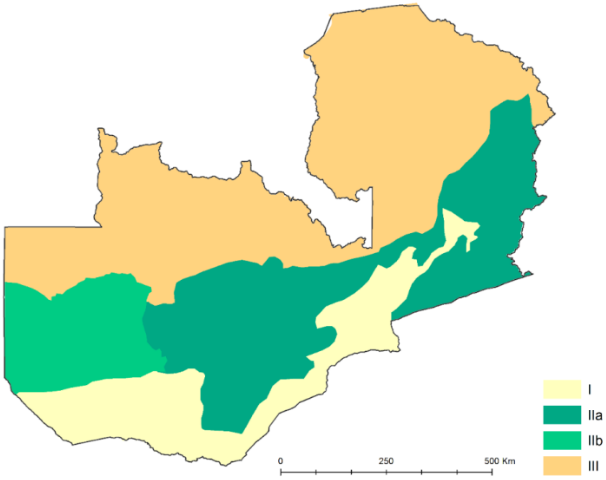
5 Agro-climatic suitability of potential feedstocks

5.1 Agroecological zones in Zambia

Zambia is divided into three main AEZs based on the average annual rainfall and soil characteristics (Figure 2). AEZ I receives less than 800 mm of rain per annum and has loamy to clay soils. This region often experiences droughts and floods, and has a shorter growing season. AEZ II is subdivided into zones IIa and IIb; both subregions receive mean annual rainfall of 800–1,000 mm.

However, AEZ IIa has fertile plateaus and a longer growing season, while AEZ IIb has loamy to sandy soils. AEZ IIa includes Central, Lusaka, Southern, and Eastern Provinces, while AEZ IIb covers Western Province. AEZ III is in the northern part of Zambia, covering parts of Copperbelt, Luapula, and North-western Provinces. Its mean annual rainfall ranges between 1,000 and 1,200 mm, and it is characterized by highly leached and acidic soils of relatively low fertility. AEZ III has a growing season of 120–150 days. Among the four AEZs, AEZ IIa and III have the highest agroecological potential (Namonje-Kapembwa et al. 2015; Siacinji-Musiwa 1999; Sitko et al. 2011).

Figure 2: Zambia's agroecological zones



Source: Chapoto and Zulu-Mbata 2015b, , reproduced with permission.

Table 8 shows the AEZs best suited for feedstock production in Zambia, while Figure 3 shows the percentage of households growing some of the feedstocks by province. What is clear is that AEZs IIa and III are the most appropriate for producing the majority of the biofuel feedstocks, with AEZ IIa having the highest potential. In AEZ III, liming, or acid-tolerant varieties, may be required to further increase the AEZ's potential. There is very limited agroecological potential in AEZ I and AEZ IIb, which cover the western and southern-most parts of the country. In addition to the two AEZs, cashew nuts and sorghum can be grown in AEZ IIb.

Table 8: Crop suitability ratings for the four agroecological zones

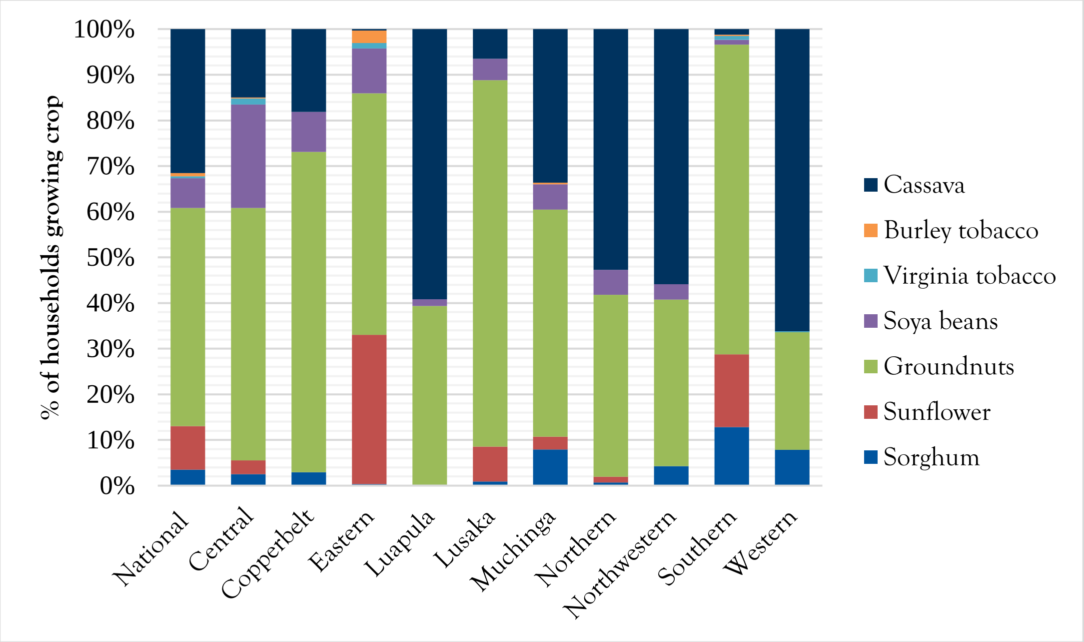
Crop	AEZ I	AEZ IIa	AEZ IIb	AEZ III	Areas with widespread smallholder cultivation in 2013–14
Seed tobacco	3	1	3	1	Eastern, Central, and Southern Provinces
Seed cotton	3	1	3	2	Eastern Province
Cashew nuts	3	2	1	2	Western Province
Soya beans	3	1	3	1	Central, Eastern, Northern, Muchinga, and Copperbelt Provinces
Sunflower	3	2	3	2	Eastern, Southern, Lusaka, and Central Provinces
Groundnuts	3	1	3	1	Eastern, Luapula, Northern, Southern, and Muchinga Provinces
Pineapples*	3	2	3	1	North-western Province
Cassava*	3	1	2	1	Luapula, Northern, North-Western, and Western Provinces
Maize	3	1	3	2	Countrywide
Sweet potatoes					Countrywide
Irish potatoes					Countrywide
Sorghum*	3	2	1	2	Southern, Muchinga, and Western Provinces
Sugarcane		1		1	Southern Province, and more recently Luapula Province

1 = Suitable; 2 = moderately suitable; 3 = marginally suitable.

Sources: based on ZDA 2011; * authors' knowledge and 2015 RALS.

In addition, areas suitable for cassava production are AEZ IIa, IIb, and III. Among these regions, major cassava-producing areas are concentrated in AEZ III (see Figure 3), where it is mainly consumed as a staple food in place of maize. Sugarcane, on the other hand, is mainly grown in the high-rainfall areas. Currently, sugar companies are located in AEZs IIa and III. For instance, Zambia Sugar Plc and Kafue Sugar's plantations are located on opposite sides of the Kafue River in Mazabuka District (Southern Province), while Kasama District (in Northern Province) is home to Kalungwishi Estates; Mansa Sugar is located in Chembe District (Luapula Province). There is, however, a limit to growing sugarcane in AEZ IIa, given that water availability has reduced following expansion by Zambia Sugar and operations by Kafue Sugar. Sunflower can be grown in AEZs IIa and III. Oil palm is mainly grown in Northern and Luapula Provinces along the Luapula river basin (AEZ III) (see *Lusaka Times* 2015; *Times of Zambia* 2015).

Figure 3: Percentage of households growing potential feedstocks



Source: based on 2015 RALS.

6 Scope for expanding feedstock production

6.1 What explains the low feedstock yields and production levels?

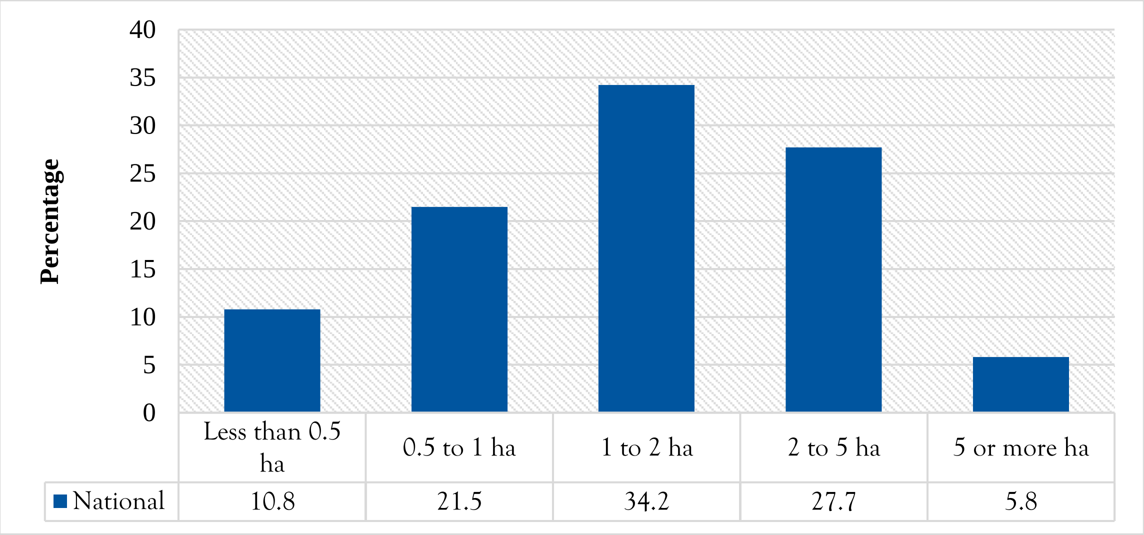
The observed low production levels for potential feedstocks are largely a consequence of the government's agricultural policy's focus on maize, with large shares of the budget allocated to two flagship programmes, namely the FISP and price support via the FRA. This has been at the expense of other key drivers of agricultural growth, such as crop diversification, extension, and agricultural research and development. It is not surprising, therefore, that the maize yield and production level is significantly higher when compared to other crops (Chisanga and Chapoto 2015).

Additionally, there have been suggestions that technologies in Zambia are not tailored to the needs of smallholder farmers. An example is the continued dissemination of D-compound fertilizer in AEZ I despite evidence showing that it does not perform well in the highly acidic soils of the north (Chapoto et al. 2016). In some cases, the lack of markets for other crops have contributed to the low production levels of some crops. Because maize has a ready market via the government's FRA buying points, most of the smallholders produce maize for sale at the expense of more profitable alternatives. This means that switching to biofuel feedstocks will partly depend on the existence of a reliable market for the smallholder producers.

There is also evidence to suggest that a lack of family labour is a contributor to the low yields and ultimately production levels for some crops. Poor or capital-constrained households have also been shown to have very low yields (Namonje-Kapembwa et al. 2015).

In addition, the majority of Zambian small-scale farmers are land-constrained, cultivating almost all the land owned or accessed, and this finding has been consistent across several studies and surveys (e.g. Chisanga and Chapoto 2015; Hichaambwa and Jayne 2014; Jayne et al. 2008). About 62.5 per cent of the smallholder farmers cultivate up to 2 ha of land (see Figure 4). This is perhaps another reason for the low production levels of potential feedstocks considered in this paper. The small land sizes are a consequence of concentrations in public investments that have yielded densely populated areas (Sitko et al. 2015). In fact, Hichaambwa and Jayne (2014) argue that increasing the smallholder land size to 10–12 ha would increase the crop surplus in Zambia, and contribute to increasing crop sales by smallholders.

Figure 4: Share of cultivated land by category



Source: based on the 2015 RALS.

In some cases, lack of tenure security, including user rights, and its effect on land investment is seen as one of the reasons for the low crop yields and production levels. Low levels of intensification and poor technology adoption rates also characterize Zambian smallholder farming. For example, Mofya-Mukuka and Hichaambwa (2015) contend that low soya bean production among smallholders is a result of recycled local seed use, suboptimal management practices, and non-application of inoculum. The low levels of hybrid seed usage for some crops are partly due to lack of access to agricultural finance by smallholders, and this also negatively impacts on yields and production of various crops. The suboptimal management practices are a direct consequence of inadequate public extension services.

Other constraints to feedstock production include the abandonment of *Jatropha* production by outgrowers, partly because the plant takes a long time to grow, so the returns are only realized years after planting the seed, and even then depend on the conditions (see Franken and Nie 2010;

Schoneveld et al. 2011). Moreover, there is limited knowledge among producers and outgrower companies on *Jatropha*, as it is a relatively new plant for commercial use.

6.2 Scope for expanding feedstock production

In light of the constraints to feedstock production alluded to in Section 6.1, there are a number of ways in which feedstock production can be increased; those related to closing the yield gap draw heavily on Namonje-Kapembwa et al. (2015). First, government expenditure will have to focus more on other important drivers of agricultural growth, such as research and development and extension. Research is vital, given climate variability and change. Through the e-voucher pilot programme in the 2015–16 rain season, it is anticipated that some of the challenges under FISP will be addressed. Moreover, because farmers are free to choose inputs, production of crops other than maize is expected to increase; whether biofuel feedstock production will increase remains to be seen. The only challenge is that there is still a need to educate farmers on technologies best suited for their respective AEZs, given the soil acidity problem.

Because the majority of the smallholders are land-constrained, infrastructure development will be key to increasing production as more areas become attractive. But there is a caveat to this; we expect that at some point labour availability or alternative power sources for crop production will become more important as the land constraint disappears. Without increasing land access, the small plot sizes are a potential barrier towards expanding feedstock production, as they can only produce a small surplus for sale even under high yields (Kuteya and Kabwe 2015).

Production is also likely to increase with increased availability of agricultural finance, which has proved a challenge among smallholders. The 2015 RALS reports that only 15 per cent of smallholders in Zambia have access to agriculture finance.

Increasing production will also require adequate agriculture extension service provision. At present, smallholders travel an average of 17 km to an extension worker, and there is scope for improvement if the funds from the oft-ineffective FRA and FISP programmes can be channelled towards extension of service delivery. In the absence of public extension, private sector extension will be key, and this can be through programmes/projects or seed and fertilizer companies.

For *Jatropha*, past experiences may hamper the desire among smallholders to engage in production—especially in places where results were catastrophic. Understanding the crop and areas best suited for growth will be important. Based on early experiences, increasing production will require capacity-building of the firms' staff first, and ultimately outgrowers. This will, in turn, help outgrowers see *Jatropha* production as a business, while improving their production management skills. In addition, improving access to finance seems one of the best ways to increase *Jatropha* production among smallholders, as the likelihood of success is dependent on wealth levels. A detailed understanding of institutional arrangements that work for Zambia will be vitally important in ensuring the success of the outgrower model.

7 Summary and conclusion

The need for climate mitigation and energy security has increased the number of countries enforcing biofuels blending mandates. Biofuels are believed to contribute less to global warming, while being a major contributor to economic growth and providing energy security amid high oil price volatility and instability in the Middle East. As a result, many multinational companies invested in the biofuels industry across Africa, but the investments were ill-timed and illresearched. The necessary policies aimed at growing the industry in most of these countries were not fully in place. Where governments made progress towards this, the rate of industry growth often outpaced the rate of policy development. Feedstocks for biofuels production were also a challenge. Many firms used *Jatropha* as a feedstock, often with a poor understanding of production under local conditions. Further, the global financial crisis of 2008–09 meant that finance availability became a challenge. Ultimately, firms either exited the industry, down-scaled operations, or ventured into other businesses.

The rise in blending mandates across the globe is likely to trigger further investments in biofuels production, especially in land-abundant countries. In Southern Africa, South Africa just enforced 5 per cent and 10 per cent blending mandates for biodiesel and bioethanol, respectively. Being a major petroleum consumer, this raises the regional demand for biofuels, and there is potential for Zambia to benefit from the global and regional trends, especially considering that it is a land-abundant country with a suitable climate for feedstock production, and has generous incentives for investment in the energy and manufacturing sectors. However, a viable biofuels industry will depend on sustained supply of cost-effective feedstocks. More importantly, the benefits from a local biofuels industry will only materialize if the right policy, legal, and regulatory framework is in place, and implemented in a way that ensures benefits to all stakeholders.

This paper reviews the Zambian biofuels industry, its current state, and the state of the policy, institutional, and legislative framework. It also identifies feedstocks that can be used for biofuels production, their current production levels, and costs of production. An analysis of the AEZs best suited for producing these feedstocks is also provided. We also discuss the scope for expanding production and the economics of biofuel production using some of the feedstocks.

Our results reveal that Zambia's potential demand for bioethanol and biodiesel in 2015 was 48.9 and 48.7 million litres respectively—almost equal. However, no commercial production is taking place to meet demand, mostly due to the effects of the factors highlighted above that led to the collapse of many firms in Southern Africa. Production among firms is usually in small quantities and mainly for internal purposes.

There has been progress towards supporting biofuels production, but more needs to be done to ensure that this materializes. The policy framework to date has no supply agreements with firms. Blending mandates have never been implemented as infrastructure is yet to be constructed. The legal, regulatory, and policy framework has not been protective of stakeholders in the past, despite clearly spelling this out in the policy documents. There is need for government to award biofuels supply contracts to firms, as this will have an impact on investment decisions among firms, and their ability to access funds from financial institutions.

Feedstock production for biodiesel is in extremely low quantities when compared to those for bioethanol. For bioethanol feedstocks, sugarcane, cassava, and maize are produced in large quantities. However, there is great potential for sorghum as a bioethanol feedstock based on research from the University of Zambia. Among potential biodiesel feedstocks, soya beans, groundnuts, and sunflower are produced in relatively large quantities. Nevertheless, there is scope for expanding feedstock production for both biofuels if yields can be increased, especially for smallholders where there are significantly large yield gaps. In terms of agro-climatic suitability, AEZs IIa and III are the most appropriate for producing the majority of the biofuel feedstocks. However, liming may be required for sorghum, for instance, in the acidic soils of AEZ III to further increase potential yields. In addition to these two AEZs, cashew nuts and sorghum can be grown in AEZ IIb.

There is scope for expanding feedstock production, if productivity can be increased. However, it appears the quickest way of significantly increasing production is likely to be through large-scale production. For small-scale farmers, access to land, markets, improved inputs, and capital will be key, more so because increased access to land impacts positively on production surplus, while also increasing crop sales.

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