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WIDER Working Paper 2017/27

Economy-wide implications of biofuel production in Zambia

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February 2017

Abstract: It is estimated that biofuel demand in South Africa will increase to 1,550 million litres by 2025 following the introduction of mandatory blending rates in 2014. Land and water constraints, however, limit domestic supply ability. Zambia, due to abundance of land, suitable climate, supportive bioenergy incentives, and geographical proximity, has the potential to meet this increased demand. Using a dynamic recursive computable general equilibrium model, we estimate the macro- and socio-economic impacts of bioethanol production in Zambia under both commercial and smallholder farming models, including and excluding bagasse co-generation. Three feedstock crops are considered: sugarcane, cassava, and sweet sorghum.

Keywords: bioenergy, bioethanol, CGE, economy-wide modelling, Zambia

JEL classification: C68, Q, 16, Q18

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This study has been prepared within the UNU-WIDER project on 'Regional growth and development in Southern Africa'.

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ISSN 1798-7237 ISBN 978-92-9256-251-9

Typescript prepared by Luke Finley.

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UNU-WIDER acknowledges specific programme contribution from the National Treasury of South Africa to its project 'Regional growth and development in Southern Africa' and core financial support to its work programme from the governments of Denmark, Finland, Sweden, and the United Kingdom.

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1 Introduction

Global biofuel demand has increased significantly over the past decade as countries have implemented fuel-blending mandates and targets as mitigation strategies to reduce greenhouse gas emissions in the transport sector. Between 2005 and 2015, biofuel production increased from less than 50 billion litres to over 130 billion litres (IEA 2016), accounting for about 4 per cent of global road transport fuel. Demand is expected to continue increasing in future as more countries mandate the use of biofuels for transportation. The IEA (2016) estimates that by 2025, biofuel production will exceed 200 billion litres.

Blending mandates have also increasingly been implemented in Africa, with many countries in the Southern African Development Community (SADC) already having mandates or targets in place. One of these countries is South Africa, which in 2014 announced blending rates of between 2 and 10 per cent for bioethanol and 5 per cent for biodiesel. Given the size of the fuel market in South Africa, this decision creates an anchor market for biofuel production in Southern Africa. Stone et al. (2015) estimate that under muted growth of only 2.7 per cent per annum (real GDP growth averaged 2.3 per cent between 2007 and 2015), demand for bioethanol and biodiesel in South Africa will increase to 1,400 and 90 million litres respectively by 2025. If flex-fuel cars are introduced, this demand could potentially increase to 2,500 and 130 million litres respectively.[1]

Zambia has the potential to become a large supplier of this demand. Its near-central geographical location, suitable climate, abundance of land, and (on paper) supportive set of bioenergy incentives provide a strong case for successful biofuel production within the country. Identified potential bioethanol crops, namely sugarcane and cassava, are also well established in the country, with large volumes produced for domestic consumption and foreign markets (Samboko et al. 2017a, forthcoming). The establishment of a biofuels sector in Zambia has the potential to promote development and poverty reduction as it introduces new employment opportunities and income streams (FAO 2013), particularly in the agriculture sector. Previous studies assessing the impact of biofuel production in developing Southern African countries such as Tanzania, Ethiopia, and Mozambique have generally found a positive impact on real economic growth and welfare in the country of study (see Ferede et al. 2013).

In this paper, we estimate the size of these potential benefits for Zambia using a dynamic general equilibrium (CGE) model. We assess the impacts of three different crops—sugarcane, cassava, and sweet sorghum—under different farming models, accounting for land and productivity constraints specific to Zambia. Given concerns about the socio-economic impacts of biofuel production, particularly its impact on food security and land displacement (Shumba et al. 2009), our analysis includes an assessment of the impact on land displacement, food security, and overall household welfare. We also assess the potential impact of electricity co-generation if coupled with sugarcane bioethanol production. The remainder of this paper is structured as follows: Section 2 discusses the potential for biofuel production in Zambia and presents the estimated costs associated with bioethanol crop production and processing; Section 3 describes the model used and outlines the scenarios and assumptions considered; Section 4 reports on the model results; and Section 5 concludes by summarizing the findings and their implications.

[1] Assuming a bioethanol mandate of 10 per cent.

2 Potential for biofuel production in Zambia

2.1 Feedstock crops and farming models

Samboko et al. (2017a, forthcoming) identify several potential crops for ethanol feedstock use in Zambia; these include sugarcane, agave, sweet sorghum, maize, cassava, pineapples, and sweet potatoes. Sugarcane and cassava are, however, highlighted as two key crops to consider given the large quantities currently produced in the country. In 2014, Zambia produced 4,015,180 and 919,417 metric tonnes (MT) of sugarcane and cassava respectively (FAO 2016).

Sugarcane in Zambia is primarily grown through commercial farming, accounting for 60 per cent of total supply and occupying about 23,000 hectares (ha) of land. Almost 400 smallholder farmers participate in sugarcane production through outgrower schemes, specifically the Kaleya Smallholder Company, Maggobo, and Manyoyo schemes. Smallholder sugarcane output is currently sold to Zambia Sugar Plc, the largest sugar producer in Zambia (Chisanga et al. 2014; Kalinda and Chisanga 2014). Plans by Kafue Sugar to develop its own outgrower model should see the number of smallholder sugarcane farmers in Zambia increase (Kalinda and Chisanga 2014). Sugarcane farming is largely irrigated, with smallholder farmers receiving water supply from core estates as part of the services provided through the outgrower schemes. The average yields of smallholder farmers are reported to compare favourably with those of commercial farmers, reaching up to 110 to 115 MT/ha (Bangwe and van Koppen 2012). The World Bank (2007) has identified the sugarcane value chain as the most profitable one involving smallholder farmers in Zambia, highlighting the sector's links to the local economy and its importance in poverty reduction.

Cassava is a low-input, drought-tolerant crop primarily grown by smallholder farmers located in the Luapula and Northern provinces of Zambia. Commercial farming accounts for less than 1 per cent of total output. Currently, cassava is largely used as a staple crop, second only to maize, with smaller shares used (in the form of cassava flour and chips) as an intermediate input into the manufacturing sector (FSRP and ACF 2010). Average cassava farming yields vary depending on the variety grown. Sitko et al. (2011) report fresh root cassava (referred to as cassava) farm yields of 3.5 MT/ha when using traditional cassava varieties and between 6 and 12 MT/ha for new varieties. Potential cassava yields from research studies have ranged between 7 MT/ha in the case of local varieties and 22 to 41 MT/ha for new varieties. Estimates from the Food Security Research Project and the Agricultural Consultative Forum (FSRP and ACF 2010) have recorded higher on-farm yields of between 18 and 20 MT/ha. The Zambian Ministry of Agriculture estimates current yields at around 11 MT/ha.

Sweet sorghum provides an alternative bioethanol feedstock to sugarcane and cassava. It can be grown more than once a year, has low input requirements, is drought-tolerant, and is a dual-purpose crop, meaning that it can be used for both bioethanol production (using the stalk) and food production (using the grain). More recent versions of the crop under study at the University of Zambia display the potential to substantially reduce the costs of bioethanol production because of higher yields per hectare (Samboko et al. 2017a, forthcoming). Current sweet sorghum yields are reported to be between 30 and 40 MT/ha, equating to between 1,530 and 2,040 litres of bioethanol. The three varieties under study at the University, named Wray, Proj1, and TS1, recorded yields of between 70 and 83 MT/ha, under research conditions which included fertilizer use as well as supplemental irrigation prior to rains (the most recent research yields have reached 100 MT/ha). This translates to bioethanol output of between 3,167 and 3,926 litres/ha (Munyinda 2016; Munyinda et al. 2014).

Estimates from Sinkala et al. (2013), which are similar to those of the Food and Agriculture Organisation (Brower and Heibloem 1986), show that sugarcane is far more water-intensive than sweet sorghum and cassava, requiring 1,500–2,500 mm of water compared to only 450–700 mm and 450–750 mm respectively in the case of sweet sorghum and cassava. As a result, sugarcane farming requires larger capital investments. This makes sweet sorghum and cassava farming more attractive to low-income smallholder farmers as they have lower input and capital costs (Sinkala et al. 2013).

2.2 Costs of bioethanol production

The choice of crop is dependent on several factors, including production cost and scale, socio-economic impact, and the potential for additional value chains from by-products. These are discussed in more detail by Sinkala et al. (2013), Samboko et al. (2017a, forthcoming), and Samboko et al. (2017b, forthcoming). Accounting for these factors as well as agro-climatic conditions, it is likely that a combination of crops is to be farmed for bioethanol production. In this section, we present estimated costs for bioethanol feedstock crop production as well as bioethanol processing. Crop yields used in the analysis are based on actual yields experienced in Zambia. For sugarcane, we use a yield of 110 MT/ha for commercial farmers and 70 MT/ha for smallholder farmers; cassava and sweet sorghum yields included are 22 and 35 MT/ha respectively. Table 1 provides a summary of reported yields for the crops considered. Crop-to-bioethanol conversion rates of 80, 167, and 51 are used for sugarcane, cassava, and sweet sorghum respectively.

Table 1: Summary of crop yields in Zambia (estimated MT/ha*)

	Sugarcane		Sweet sorghum		Fresh root cassava	
Farm size	Small	Large	Small	Small: high-yielding	Small	Small: high-yielding
Yield (MT/ha)						
Shumba et. al (2009)	112–120		30–40	40–60	-	
Bangwe and van Koppen (2012)	110–115	-	-	-	-	-
Sitko et al. (2011)	-	-	-	-	3.5–12	-
	-	-	-	-	*7–41*	-
Sinkala et al. (2013)	-	110	-	-	-	-
Tembo and Sitko (2013)	-	-	-	-	2.85	-
Sinkala (personal communication, Prof. Thomson Sinkala, 24 May 2016)	-	-	-	-	11	-
Samboko et al. (2017a, forthcoming)	-	-	-	-	5.87	13.79
	-	-	-	*70.2–82.5*	-	-
Ethanol conversion rate (litre/mt)						
Shumba et. al (2011)	80		55		-	
Sinkala et al. (2013)	80		45		200	

Sinkala (personal communication, Prof. Thomson Sinkala, 14 November 2016)	-	-	167
Samboko et al. (2017a, forthcoming)	-	*51*	-
Water requirement (mm)**	1,500–2,500	450–700	400–750

Notes: * Italics indicate yield estimates under research condition.

Source: ** Sinkala et al. (2013).

2.2.1 Bioethanol crop farming

Sugarcane, cassava, and sweet sorghum production costs are calculated using data from Sinkala et al. (2013), Sinkala (2015), and enterprise budget data collected by Samboko et al. (2017a, forthcoming), respectively. Sugarcane costs from Sinkala et al. (2013) are for commercial farmers. We estimate smallholder costs from these by applying commercial-to-smallholder budget ratios from a similar study for Tanzania (Arndt et al. 2012). Expenditure on seed in sugarcane production from Sinkala et al. (2013) has been amended as suggested by the Indaba Agricultural Policy Research Institute (IAPRI) to reflect average annual expenditure. Table 2 summarizes feedstock production by crop and type of input.

Table 2: Feedstock production costs by crop, US$/ha (2016 prices)

Feedstock farm size	Large-scale	Smallholder		
	Sugarcane	Sugarcane	Sweet sorghum	Cassava
Seed	181.6	181.6	7.3	45.0
Chemicals	860.3	749.2	141.3	-
Food	-	-	-	3.0
Wood and paper	-	-	8.3	-
Business services	311.3	124.6	30.1	42.2
Financial services	40.8	45.4		30.0
Trade services	95.3	37.8		-
Transport	116.5	116.5	23.1	40.0
Labour	257.9	460.2	170.8	278.0
Land	95.8	21.9	19.6	123.5
Capital	718.4	200.1	66.0	205.9
Total cost	2,677.9	1,937.5	466.6	767.5
MT/ha	110.0	80.0	35.0	22.0
litres/ha	8,800.0	6,400.0	1,785.0	3,674.0
Total cost per litre	0.304	0.303	0.261	0.209

Source: Own calculations; Sinkala et al. (2013); personal communication, Prof. Thomson Sinkala, 24 May 2016; Samboko et al. (2017a, forthcoming).

Calculated bioethanol feedstock crop costs range between US$0.209/L and $0.304/L. Cassava is found to be the cheapest feedstock crop, costing 30 per cent less than sugarcane and 20 per cent less than sweet sorghum. The lower cost is driven by the relatively lower expenditure on intermediate inputs, including fertilizer, which is not used in cassava farming. Cassava farmers spend a larger share of their budget on factor returns (i.e. payments to land, labour, and capital). Factor payments account for almost 80 per cent of total expenditure, compared to 40 and 55 per cent respectively under sugarcane and sweet sorghum. Increased cassava production would therefore have larger gross value added (GVA) impacts per unit of output than increased sweet sorghum or sugarcane production, while the latter has stronger links with the rest of the economy, particularly the chemicals sector.

Smallholder farms are more labour intensive than commercial farms, with returns to labour accounting for almost 25 per cent of sugarcane smallholder expenditures and only 10 per cent of commercial farming budgets. Cassava and sweet sorghum are also labour intensive, with 40 per cent of expenditure going on wages. Commercial sugarcane farmers spend almost 30 per cent of their budget on returns to capital. Interestingly, cassava farmers also spend a relatively large share of their budget on payments to capital.

While feedstock costs per litre of bioethanol are lower in the case of cassava and sweet sorghum, more land is needed than for sugarcane due to lower yields per hectare. To produce 1 million litres of bioethanol, 130,682 ha of land is needed under sugarcane production (assuming the current 60–40 split between commercial and smallholder farmers), relative to 272,183 and 560,224 ha under cassava and sweet sorghum production respectively. Cassava and sweet sorghum, however, require half the amount of water needed for sugarcane farming (see Table 1).

2.2.2 Bioethanol processing

No commercial production of bioethanol takes place in Zambia (Samboko et al. 2017a, forthcoming). As a result, there is no Zambia-specific data available for bioethanol processing. Sinkala et al. (2013) estimate bioethanol processing costs for Zambia for sugarcane, cassava, sweet sorghum, and agave crops. These estimates are derived from a 2010 study by the Asia Pacific Economic Cooperation forum (APEC Secretariat 2010) in which the processing costs for Brazil, Malaysia, and the USA are calculated for a ten-year period. These costs are included in this study and presented in Table 3, accounting for the feedstock costs from Table 2.

Table 3: Bioethanol production costs by crop, US$/L (2016 prices)

Feedstock farm size	Large-scale	Smallholder		
	Sugarcane	Sugarcane	Sweet sorghum	Cassava
Feedstock unit costs	0.304	0.303	0.261	0.209
Capital cost and interest	0.000	0.000	0.000	0.057
Chemicals/enzymes	0.057	0.057	0.057	0.019
Energy/utility	0.019	0.019	0.019	0.085
Operations/maintenance	0.038	0.038	0.038	0.028
Unforeseen	0.019	0.019	0.019	0.019
Total cost	0.436	0.435	0.394	0.417

Source: Own calculations; Sinkala et al. (2013).

The production cost of bioethanol in Zambia is calculated to be between US$0.394/L and $0.436/L depending on the feedstock crop chosen. Sweet sorghum-based bioethanol is found to have the lowest factory gate price. The price of ethanol from cassava is about $0.02 higher due to higher "non-feedstock" processing costs. "Non-feedstock" ethanol processing costs related to cassava are about 57 per cent higher than those for sweet sorghum and sugarcane because of larger initial investment costs, as well as higher energy and utility costs.

Bangwe and van Koppen (2012) estimate that the crop yields of smallholder sugarcane farmers average 110 MT/ha. This is higher than our assumed yield of 70 MT/ha. If yield estimates by Bangwe and van Koppen (2012) were realized, the price of ethanol produced using smallholder sugarcane would decrease to $0.352/L. Similarly, higher yields for sweet sorghum as experienced under the University of Zambia's research programme would lead to lower bioethanol prices. Sweet sorghum yields of 82.5 MT/ha would lower bioethanol costs to only $0.243/L. This is competitive with factory gate prices estimated for Mozambique (Hartley et al. 2017, forthcoming).

3 Modelling methodology

3.1 A dynamic recursive CGE model for Zambia

A dynamic recursive CGE (DCGE) model for Zambia is used to measure the economy-wide impacts of producing bioethanol in the country. The model is based on a 2007 Social Accounting Matrix (SAM, Chikuba et al. 2013) consisting of 44 industries and commodities, 4 labour groups, and 5 rural and urban household groups. Labour categories are defined by education levels (i.e. incomplete primary, completed primary, completed secondary, and completed tertiary). Households are grouped into quintiles according to income. Other institutions (i.e. government, enterprises, and the rest of the world) are also represented.

Behavioural equations capture the decision-making process of industries and households, which maximize profits and utility subject to costs and purchasing power respectively. Producers consume both domestic and imported intermediate goods and services as well as factors of production. Production factors include capital, labour, and, in the case of agriculture, land. The consumption of intermediate goods and services is governed by Leontief functions, while the consumption of production factors is specified according to constant elasticity of substitution (CES) functions. As a result, fixed shares of goods and services are required in the production process, but production factors can be substituted according to changes in their relative prices.

For this specific model, we assume that each activity only produces one commodity. Commodities are sold to other industries as intermediate inputs and to households, government, and the rest of the world for final consumption. The quantity of commodities provided to domestic versus international markets is based on relative prices and is governed by a constant elasticity of transformation (CET) function. Similarly, the volume of goods and services imported is also based on relative prices and is governed by an Armington function. We assume that Zambia is too small to directly affect global prices, which therefore remain fixed.

Households earn an income from providing labour, land, and capital assets to industries, and from government and foreign transfers. Returns to foreign labour, land, and capital are repatriated. Households consume both domestic and foreign commodities, pay taxes, transfer money abroad, and save. Consumption is based on a linear expenditure system (LES) of demand.

Structural equations ensure macroeconomic consistency between incomes and expenditures within the model. Closure rules are used to describe the functioning of the economy; these include the behaviour of exchange rates, investment, government savings, prices, and quantities of factors of production. In this paper, we assume that the exchange rate adjusts to absorb shocks to the economy, while foreign savings remain fixed. The level of investment is determined by total savings in the economy (i.e. private, government, and foreign). Government savings adjusts for changes in income and expenditure; all tax rates remain unchanged. The domestic price index is used as the model numeraire. To fully assess the impact on resource shifts, we assume that all labour and land in the economy is initially fully employed. Capital, not used in the biofuel industry, is also fully employed and is activity-specific. Existing capital therefore cannot shift to other sectors in the economy. Capital used in the biofuel industry is considered unemployed and can therefore increase at no cost to the economy.

3.2 Structure of the Zambian economy

In 2007, the agriculture sector accounted for 13.8 per cent of real GDP and 8.2 per cent of total exports in Zambia. The sector employed 71.3 per cent of the total workforce but only accounted for 16.3 per cent of total labour income. About 90 per cent of employment in the sector is comprised of low-skilled workers with less than completed secondary education. The agriculture sector is a net exporter. Primary agriculture exports include maize, tobacco, and cotton. Small amounts of agriculture food crops are imported, mostly cereal and horticulture crops, but this accounts for less than 2 per cent of domestic demand. Processed food imports are also relatively small, with the bulk of demand being satisfied by domestic production.

Mining is the main earner of foreign income, accounting for 71.4 per cent of total exports, followed by manufacturing (10.5 per cent). Manufacturing exports largely consist of metal products and machinery. Food processing was the largest manufacturing sub-sector in 2007, accounting for 5 per cent of total real GDP. The services sector comprised the largest share of GDP in 2007, primarily due to the wholesale and retail trade services sub-sector (See Table 4).

Table 4: Structure of Zambia's economy, 2007

	Share of total (%)					Exports/ output (%)	Imports/ demand (%)
	GDP	Labour income	Employment	Exports	Imports		
Total GDP	100.0	100.0	100.0	100.0	100.0	12.0	16.4
Agriculture, forestry, and fishing	20.0	16.7	71.3	8.6	1.5	5.4	1.3
Food crops	10.2	4.3	18.5	3.9	0.6	6.3	1.4
Other agriculture	3.6	4.5	19.2	4.3	0.6	16.8	3.8
Forestry and fishing	6.2	7.9	33.6	0.0	0.0	0.0	0.0
Mining	4.9	2.0	2.0	71.4	0.0	89.6	0.0
Manufacturing	9.7	6.1	3.5	10.5	77.7	5.0	40.3
Food processing	5.8	4.0	2.2	5.0	4.6	4.5	5.8
Other manufacturing	3.9	2.1	1.2	5.6	73.1	5.8	63.2
Other industries	15.2	13.8	2.0	0.4	0.3	0.4	0.3

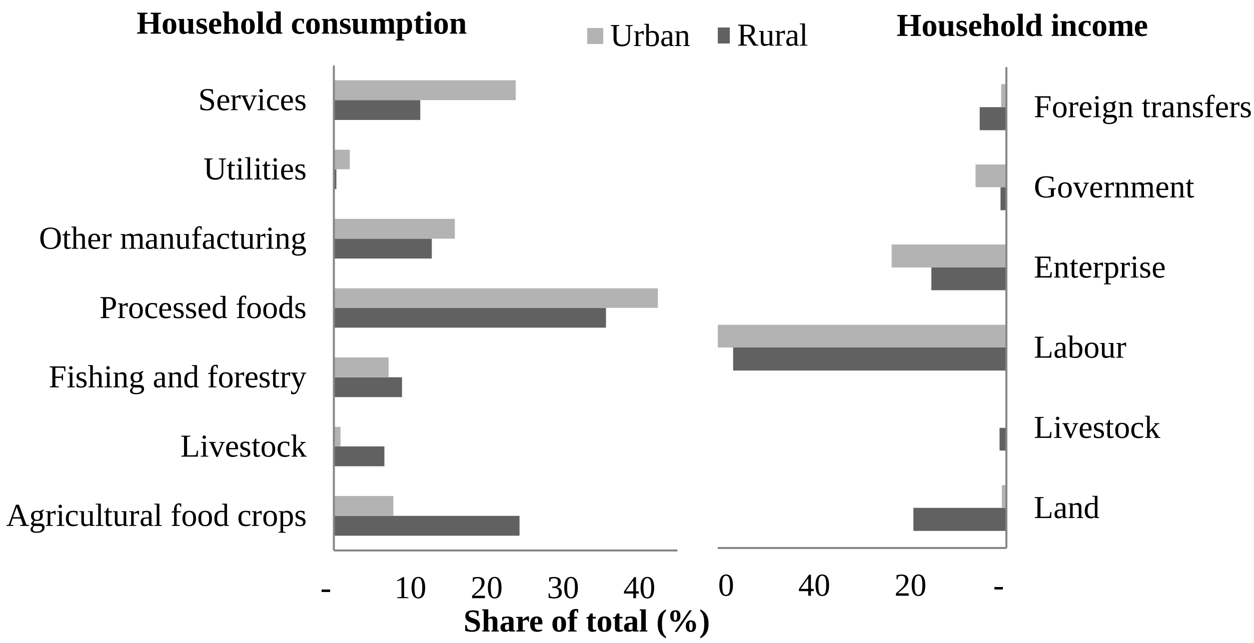
Services	50.2	61.3	21.2	9.5	20.8	3.3	6.9

Source: 2007 Zambia SAM (CSO 2011).

Food consumption makes up the largest share of rural and urban household spending in Zambia. In 2007, food expenditure accounted for 42 and 36 per cent of total commodity consumption in rural and urban households respectively. Processed foods make up the largest share of urban household diets (about 85 per cent of total food expenditure), with agricultural food crop consumption comprised mainly of horticulture crops such as fruit and vegetables, and pulses. While rural households spend a significant share of their budgets on processed foods, they also spend a relatively large share of their budgets on agricultural food crops, primarily cassava and maize.

Household incomes are primarily derived from the provision of labour (Figure 1). Wage income accounts for 68 and 57 per cent of total urban and rural income respectively; however, 72 per cent of total labour returns are paid to urban households. Urban households also receive a relatively large share of their incomes from capital returns (24 per cent) and government transfers (6 per cent). Rural household incomes are more diverse, with returns to land and capital as well as foreign transfers comprising around 40 per cent of total income. Capital returns to rural households comprise only 23 per cent of total capital returns in the economy, with the remaining 77 per cent paid to urban households.

Figure 1: Rural and urban household consumption and income, 2007



Source: 2007 Zambia SAM (CSO 2001).

3.3 Baseline growth path

The 2007 structure of the Zambian economy described above serves as the starting point for the defininition of relationships and parameters in the DCGE model. In the baseline scenario, we extend this structure over an 18-year period, i.e. 2007 to 2025. Exogenous parameters such as supply of labour and land, government expenditure, and foreign savings are updated externally based on historical trends for Zambia. Capital stocks are updated in each period by investment from the previous period, accounting for depreciation. Increases in sector capital stocks are a function of profitability in the previous period as well as share of total capital stock. Table 5 presents these key assumptions.

In addition, for the 2007–14 period, total factor productivity growth rates are set such that the model matches average annual sector growth over the period as far as possible. Baseline average annual growth over the 2015–25 period averages 5.1 per cent in line with the IMF's April 2016 forecast for Zambia (IMF 2016). Total factor productivity increases at an average rate of 0.8 per cent per annum to replicate the IMF growth outlook.

For the purposes of this study the baseline growth rate is somewhat arbitrary. Our focus is on the impact of bioethanol production in Zambia, which is captured by the differences between the baseline and the various scenario outcomes.

Table 5: Core macroeconomic assumptions and results, 2015–25

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Baseline	Sugarcane, status quo	Sugarcane, 20–80	Sugarcane and co-generation	Cassava	Cassava and displacement	Sweet sorghum
Average annual growth rate (%)							
Total GDP	5.1	5.129	5.119	5.158	5.139	5.107	5.118
Labour supply	4.0	4.000	4.000	4.000	4.000	4.000	4.000
Capital stock	4.7	4.681	4.679	4.684	4.678	4.675	4.676
Livestock stock	0.6	0.600	0.600	0.600	0.600	0.600	0.600
Land supply	0.6	1.287	1.373	1.287	1.981	1.309	3.264
Deviation from baseline final year value, 2025 (%)							
Real exchange rate*	-	0.399	0.446	0.306	0.668	1.187	0.603
Real food price	-	0.018	0.030	0.009	0.144	1.397	0.113

Notes: * A positive value indicates an appreciation.

Source: Authors' calculation based on the results from the Zambian CGE model.

3.4 Including the biofuel industry

The biofuel industry, which includes both the feedstock farming and the ethanol processing sectors, is included in the SAM using the technology vectors described in Table 2 and Table 3 in Section 0. In the baseline scenario, production by these sectors is set to (almost) zero so that their activity is not visible. Capital for commercial farming and ethanol processing is assumed to be sourced from international markets. Smallholder sugarcane farming is also assumed to receive capital from international markets, as smallholder farmers generally produce for sugar companies which are assumed to be foreign-owned. Thus, returns to capital (after tax) from these farmers and from ethanol producers are repatriated using a separate and newly introduced factor account, i.e. fbio-l. Non-sugarcane smallholder farmers are expected to receive international donor funding with (after tax) returns transferred in the standard way to domestic households, primarily the wealthiest 40 per cent of the population in rural areas, also using a newly introduced factor account, i.e. fbio-s.

The new bioethanol processing industry creates a demand for feedstock crops to be used in processing. To simulate the expansion in ethanol production, we exogenously increase the supply of land given to feedstock farmers for the specific scenario. Farmers draw in capital, labour, and intermediate inputs through their production processes. Feedstock outputs are used by the processing sector, along with capital, labour, and intermediate inputs, to produce bioethanol.

Bioethanol processing can also lead to increased supply of non-biofuel products in the economy through the development of the by-product industry. Examples of by-products from bioethanol production include electricity through co-generation as well as animal feed. Sugarcane waste (i.e. bagasse) is usually used by sugar mills for electricity production for their own use. In most cases, however, there is an excess supply that can be sold to the national grid. Mauritius has been very successful in using bagasse for electricity production. In 2013, the country produced around 475 GWh of electricity from bagasse, comprising just over 16 per cent of total electricity production and 20 per cent of local electricity demand (Ministry of Energy and Public Utilities 2015). Deepchand (2005) estimates that in 2002, Africa had the potential to produce 10,000 GWh of electricity from existing sugarcane waste. Zambia specifically was estimated to have potential co-generation power of between 147 and 231 GWh (between 1 and 2 per cent of electricity consumption in 2007) under sugarcane production levels of 2.1 million MT. These estimates are based on conversion factors of 70 kWh/tonne and 110 kWh/tonne respectively. To illustrate the added benefit of additional value chains, the SAM is further adapted to include the potential for co-generation from sugarcane waste. The technology vector for this sector is like that of the bioethanol processing sector but also includes the cost of capital of generating electricity using bagasse. Electricity is a by-product from bioethanol production, adding to domestic supply in the country. Based on Deepchand's (2005) estimates, we assume that 70 kWh of electricity is produced from one tonne of sugarcane. Since co-generation is essentially free, the value of the electricity produced is, in the SAM, added to the operating surplus of the bioethanol industry. As a result, this activity becomes more profitable.

We assume that all bioethanol is exported. It is likely that some of the bioethanol produced may be used domestically. Samboko et al. (2017a, forthcoming) estimate potential demand for bioethanol and biodiesel in 2015 at 48.9 and 48.7 million litres respectively. Either way, this does not have a significant impact on the results, as domestic use of bioethanol would reduce exports of bioethanol but also reduce imports of petroleum.

3.5 Scenarios and assumptions

Based on the discussion above, we consider the economic implications for Zambia if it were to provide South Africa with 1,400 million litres of bioethanol by 2025. We consider six scenarios, described in Table 6. The scenarios are designed such that the economy-wide impacts of (i) different feedstock crops; (ii) different farming models; (iii) by-products, specifically co-generation; and (iv) land displacement can be assessed.

Table 6: Scenarios

	Scenario	Description
1	Sugar, status quo	Bioethanol production using sugarcane (i.e. 60% commercial; 40% smallholder)
2	Sugar, 20–80	Bioethanol production using sugarcane (i.e. 20% commercial; 80% smallholder)
3	Sugar, status quo and co-generation	Bioethanol and electricity production using sugarcane (i.e. 60% commercial; 40% smallholder)
4	Cassava	Bioethanol production using cassava
5	Cassava and displacement	Bioethanol production using cassava, including the cost of land displacement (50% of smallholder farming land needs)
6	Sweet sorghum	Bioethanol production using sweet sorghum

Source: authors.

Differences between Scenarios 1 and 2 assess the impact of increased smallholder farming. In Scenario 2, 80 per cent of the share of sugarcane crop for bioethanol use is sourced from smallholder farmers and 20 per cent comes from commercial crop producers. The bulk of sugarcane produced in Zambia, approximately 60 per cent, is currently grown by large-scale farmers (Kalinda and Chisanga 2014). Smallholder farmers are expected to enjoy larger positive welfare effects given their higher labour intensity.

The impact of co-generation is assessed in Scenario 3. The production of 1,400 million litres is estimated to result in approximately 1,225 GWh of electricity, lowering electricity prices and therefore production costs, particularly for energy-intensive sectors. Scenarios 4 and 6 consider the impacts of alternative bioethanol feedstock crops, primarily cassava and sweet sorghum.

The impact of biofuel production on food security is a significant concern for low-income countries, as it is argued that it could raise food prices (Arndt et al. 2012). Sinkala et al. (2013) argue that in the case of Zambia this is not likely to be an issue, as (i) an excess of productive agricultural lands is available; (ii) open-ended food prices in Zambia (and Africa in general) are more lucrative than the capped prices that biofuels would offer; (iii) the biofuels industry stimulates high-yield crop production approaches because of the limited radius of feedstock viability; and (iv) food availability in biofuel production areas is part of the biofuel's competitive advantage for the industry's survival. Samboko et al. (2017b, forthcoming) agree that, apart from current limited food availability in the Western and Muchinga provinces, food security is not an issue in Zambia. Crop displacement is therefore not considered in the bulk of our scenarios. Cassava farming in Zambia is largely for domestic consumption. Contracts to supply cassava for biofuel processing could—although it is unlikely—lead to the displacement of land. To illustrate the potential impacts that land displacement might have on the Zambian economy and food security, we consider a 50 per cent rate of land displacement (following Arndt et al. 2012) in Scenario 5.

Climate variability may potentially have a significant impact on crop production yields in Zambia, particularly in the case of rain-fed crops such as cassava and sweet sorghum. For irrigation-based sugarcane, the impacts are likely to be smaller, translating rather into higher irrigation costs. These impacts would lead to higher feedstock crop prices, raising the cost of bioethanol and potentially making it less competitive relative to alternative fuels and suppliers. These impacts are not considered in this paper and provide an avenue for further analysis.

4 Results

This section reports on the modelling results. Unless specified otherwise, the results are presented as the percentage-point change in the average annual growth rate over the 2015–25 period relative to the baseline scenario. The 'Total GDP' result of 0.029 for Scenario 1 in Table 7: Sector growth is therefore interpreted as an increase in the average annual growth rate from 5.1 per cent in the baseline to 5.129 per cent (see Table 5).

4.1 Macroeconomic impacts

The development of a bioethanol industry in Zambia, based on the single product value chain assumption used, has a positive impact on average annual real GDP growth, which increases by between 0.03 and 0.04 percentage points per annum (Scenarios 1, 4, and 6). The largest gains in growth are experienced under Scenario 4, in which ethanol is produced from cassava. Relative to other crops, cassava has the largest value added per unit of output produced.[2] This is followed by sugarcane (Scenarios 1 and 2), with sweet sorghum reflecting the smallest gains to real GDP growth (Scenario 6).

Expanding the bioethanol industry to include the production of by-products such as electricity has the potential to amplify gains to the economy. Average annual real GDP growth increases by 0.058 percentage points in Scenario 3, relative to 0.029 percentage points in Scenario 1. By 2025, electricity produced from bioethanol production accounts for about 4 per cent of total electricity demanded. The increase in electricity supply lowers electricity costs, raising profitability as well as household purchasing power. This positively affects production (particularly for energy-intensive producers) and consumption.

The assumed displacement of land due to bioethanol crop production in Scenario 5 lowers the gains to real GDP growth, as it reduces the land resources available for other agricultural use. Non-bioethanol feedstock production declines are greater under this scenario, resulting in larger price increases, which has knock-on effects on the rest of the economy through the interlinkages between sectors. The overall impact on real GDP growth, however, remains positive, with average annual real GDP growth increasing by 0.007 percentage points relative to the baseline.

Increasing the share of smallholder-farmed sugarcane used for bioethanol production (Scenario 2) has a marginally smaller impact on real GDP growth than using the status quo production model (Scenario 1). This is because the value added of commercial sugarcane farmers is marginally larger than that of smallholder farmers. Smallholder sugarcane farming is also more labour intensive than commercial farming. This places upward pressure on wages and production costs in the economy.

The expansion of bioethanol production is simulated through an increase in land allocated to feedstock producers. Thus, land supply increases relative to the baseline scenario (see Table 5).

[2] Value-added contribution refers to the share of budget spent on returns to production factors, i.e. labour, land, and capital, per unit of output.

Based on current crop production approaches, approximately 17.5, 8.3, and 27.5 million MT of sugarcane, cassava, and sweet sorghum, respectively, is needed to produce 1,400 million litres of ethanol by 2025. This requires an increase in average annual land supply growth of 0.7, 1.4, and 2.7 percentage points, adding 182,955, 381,056, and 784,314 ha to total land used in Zambia. Greater land supply growth is needed under the cassava and sweet sorghum scenarios, as their yields per hectare are smaller relative to sugarcane. Similarly, smallholder farmers also require more land input than commercial farmers. This is illustrated in Scenario 2, where land supply grows by an additional 0.09 percentage points relative to Scenario 1. Land supply growth under the displacement scenario (Scenario 5) is marginally smaller, as 50 per cent of the land required is assumed to come from current agricultural activities.

Labour is assumed to be fully employed. Labour resources therefore shift away from other sectors into the biofuel industry to meet the bioethanol target of 1,400 million litres. The increase in demand for labour results in an increase in wages as firms complete for a limited resource. This has a negative impact on sectors with price-sensitive demand and thus their production decreases, thereby constraining the positive impact on real GDP. These sectors, however, release resources to be used elsewhere in the economy. Cassava is one sub-sector that benefits from this endogenous shift in resources. This is an important finding given the importance of cassava for food security in Zambia, particularly in rural areas.

Food prices, however, increase because of higher production costs, lower levels of processed-food production, and increased demand from households due to higher incomes. Food price increases are larger in the case of cassava and sweet sorghum as they are more labour intensive than sugarcane. The higher demand for labour under these crops (Scenarios 4 and 6) results in larger increases in average wages. The assumed displacement of land in Scenario 5 has a particularly significant impact on food price increases, as food crop production, and hence food supply, decreases relative to the baseline scenario. The inclusion of co-generation in Scenario 3 limits the increase in food prices, as lower electricity prices—due to additional supply from bioethanol-processing industries—provide some relief to rising production costs. The local currency strengthens to maintain the current account balance.

4.2 Sector and employment impacts

Table 7 summarizes the impacts on sector gross value added. Real GVA increases across most sectors relative to the baseline scenario. The agriculture and manufacturing sectors experience the largest increases in average annual real GVA growth due to the expansion of the bioethanol industry. Gains in these sectors are larger under the cassava and sweet sorghum scenarios due the larger value-added contributions of the crops and their lower output prices.

The mining sector experiences the largest declines in GVA growth relative to the baseline scenario. The decline in mining activity is largely driven by the real appreciation in the local exchange rate, which makes the sector less competitive internationally. Mining export volumes are between 3 and 6 per cent lower by 2025 relative to the baseline scenario. Sizeable declines are also experienced in the forestry sector, while fishing activity increases due to increased household demand. Smaller decreases are experienced in the services sector as it has relatively strong links with the bioethanol industry, particularly through the industry's use of transport and business services. Electricity-intensive industries, such as mining, construction, and heavy manufacturing, perform marginally better in Scenario 3 due to lower electricity prices.

Table 7: Sector growth

		Deviation from baseline growth rate (%-pt)					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Baseline growth, 2015–25 (%)	Sugarcane, status quo	Sugarcane, 20–80	Sugarcane and co-generation	Cassava	Cassava and displacement	Sweet sorghum
Total GDP	5.1	0.029	0.020	0.058	0.040	0.007	0.018
Agriculture	4.0	0.173	0.157	0.181	0.237	0.153	0.231
Food crops	3.1	0.024	0.024	0.020	0.038	−0.101	0.009
Other agriculture	4.6	−0.026	−0.037	−0.027	−0.020	−0.125	−0.038
Forestry and fishing	4.9	−0.081	−0.092	−0.053	−0.123	−0.133	−0.112
Mining	3.1	−0.287	−0.311	−0.187	−0.461	−0.445	−0.397
Manufacturing	5.1	0.098	0.079	0.384	0.181	0.138	0.084
Food processing	4.8	−0.013	−0.018	−0.017	0.014	−0.037	−0.001
Other manufacturing	5.4	−0.029	−0.036	−0.020	−0.050	−0.084	−0.046
Utilities and construction	6.4	−0.007	−0.014	−0.028	0.021	0.012	−0.027
Services	5.2	0.004	−0.002	0.003	−0.012	−0.037	−0.020

Source: Authors' calculation based on the results from the Zambian CGE model.

The bioethanol industry could potentially create between 55,000 and 270,000 new employment opportunities depending on the feedstock crop chosen.[3] Cassava- and sweet sorghum-based bioethanol production creates 3.2 and 4.8 times more jobs than sugarcane-based bioethanol production. The shift to more smallholder sugarcane in Scenario 2 results in around 30,000 additional jobs being created, as smallholder farming is more labour intensive than commercial farming. Jobs created in the bioethanol industry are created largely through the crop activity, as the processing of ethanol is relatively capital intensive.

Due to our full employment assumption, the increase in demand for labour from the bioethanol industry causes a shift in labour out of less profitable sectors, which experience a decline in activity relative to the baseline. The sectors that experience the largest declines in average annual growth are also those that experience the largest decreases in employment relative to the baseline scenario. The greater labour needs of smallholder farmers result in larger employment shifts out of non-bioethanol production sectors. This is evident when comparing Scenarios 2, 4, and 5 to Scenario 1. In Scenario 3, the shift in employment is also affected by lower electricity prices due to increased supply. Under this scenario, electricity-intensive industries benefit from the lower electricity price, which reduces the decrease in production and hence outflow of labour relative to Scenario 1. Table 8 presents the changes in employment by sector for the different scenarios.

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[3] No employment numbers are available for the bioethanol industry. Information in the technology vectors imposed does, however, provide information on the wage bill cost. Using the implied average wage for the agriculture, fishing, and forestry sector from the 2008 Labour Force Survey for Zambia (CSO 2011), we can estimate the number of jobs per unit of output. This is then scaled up by the level of output to estimate the potential number of jobs in the bioethanol industry.

Table 8: Sector employment

		Deviation from baseline growth rate (%-pt)					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Baseline growth, 2015–25 (%)	Sugarcane, status quo	Sugarcane, 20–80	Sugarcane and co-generation	Cassava	Cassava and displacement	Sweet sorghum
Total GDP	4.0	0.000	0.000	0.000	0.000	0.000	0.000
Agriculture	4.2	0.107	0.152	0.120	0.178	0.310	0.283
Food crops	3.5	0.015	0.002	0.006	0.024	0.589	−0.033
Other agriculture	4.8	−0.027	−0.041	−0.031	−0.007	0.007	−0.037
Forestry and fishing	4.2	−0.111	−0.128	−0.075	−0.170	−0.182	−0.160
Mining	1.2	−0.764	−0.824	−0.507	−1.225	−1.173	−1.065
Manufacturing	3.3	−0.056	−0.068	−0.054	−0.052	−0.132	−0.072
Food processing	3.1	−0.044	−0.054	−0.051	−0.005	−0.096	−0.038
Other manufacturing	3.6	−0.082	−0.098	−0.066	−0.131	−0.195	−0.132
Utilities and construction	5.3	−0.024	−0.037	−0.053	0.009	0.000	−0.064
Services	3.7	−0.003	−0.010	−0.003	−0.026	−0.055	−0.035

Source: Authors' calculation based on the results from the Zambian CGE model.

The employment shifts illustrate the significance of the assumed employment constraints on the economy-wide impacts of bioethanol. Constrained labour will result in decreased activity in sectors less able to compete, and smaller overall economic benefits. If this constraint is released (see Section 0), the GDP gains from bioethanol processing may be higher and may lead to increased employment.

4.3 Household welfare and food security

Bioethanol production in Zambia results in an increase in both rural and urban household welfare (see Table 9). Welfare is measured using per capita real consumption. The rise in per capita consumption is the result of higher incomes earned from labour, as wages increase, as well as returns from new land and capital. Enterprise incomes decrease relative to the baseline scenario due to decreased profitability in non-bioethanol sectors.

Welfare gains are largest under the cassava and sweet sorghum scenarios (i.e. Scenarios 4 and 6), as incomes earned from returns to land, labour, and capital are relatively higher. Land incomes are higher because the stock of land supply increases at a faster rate, while labour income increases because economy-wide wages are higher due to increased demand. Unlike in the case of sugarcane, capital (fbio-s) returns are redistributed to domestic households, raising their incomes. In the case of sugarcane, capital (fbio-l) returns are repatriated to foreign investors.

Contrary to expectations, welfare gains under Scenario 2 (i.e. a higher share of smallholder-produced sugarcane) are marginally lower than under Scenario 1. This is driven by relatively smaller increases in income from land and high-skilled labour. Land supply increases in Scenario 2 are larger than in Scenario 1; thus, the return to land and hence income from land is lower in Scenario 2. Smallholder sugarcane farmers employ more low-skilled labour than commercial sugarcane farmers. By increasing the share of smallholder sugarcane used in bioethanol processing, the demand for low-skilled workers is raised relative to Scenario 1, resulting in higher wages for low-skilled workers. This places upward pressure on production costs and, as seen in Table 7, non-bioethanol sectors reduce activity at a faster pace. This reduces the demand for higher-skilled labour and, because a closure of full employment is assumed, the average wage and hence income for high-skilled workers decreases relative to Scenario 1. While rural households are primarily affected by the change in land income, urban households are affected by the change in skilled labour income as well as lower enterprise income as firms reduce activity.

Interestingly, Scenario 3 also results in lower welfare impacts than does Scenario 1 despite overall GDP gains being stronger. Co-generation decreases the price of electricity, as it not only adds to existing supply but is also produced at a lower price. The lower electricity price encourages increased capital use, lowering the demand for labour, resulting in lower wages relative to Scenario 1. Returns to land are also lower in Scenario 3 than in Scenario 1, as non-bioethanol agriculture sub-sectors experience slower growth, thereby somewhat alleviating the non-bioethanol land constraint.

Welfare gains are larger for rural households as they receive the bulk of returns from land. Approximately 90 per cent of returns to land are paid to rural households. Urban household incomes are also dampened by lower returns from enterprise income.

Table 9: Per capita real consumption

		Deviation from baseline growth rate (%-pt)					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Baseline growth, 2015–25 (%)	Sugarcane, status quo	Sugarcane, 20–80	Sugarcane and co-generation	Cassava	Cassava and displacement	Sweet sorghum
Rural	2.4	0.012	0.010	0.003	0.091	0.000	0.058
Quintile 1	2.0	0.015	0.014	0.003	0.112	−0.006	0.074
Quintile 2	2.2	0.015	0.014	0.003	0.107	−0.004	0.070
Quintile 3	2.3	0.014	0.012	0.003	0.102	−0.002	0.065
Quintile 4	2.4	0.012	0.010	0.002	0.093	0.005	0.061
Quintile 5	2.6	0.009	0.006	0.002	0.069	0.000	0.042
Urban	1.1	0.005	0.004	0.001	0.007	−0.015	0.003
Quintile 1	0.9	0.009	0.012	−0.002	0.019	−0.024	0.019
Quintile 2	1.0	0.007	0.008	−0.002	0.014	−0.023	0.014
Quintile 3	1.1	0.006	0.006	−0.001	0.012	−0.023	0.010
Quintile 4	1.1	0.005	0.005	0.000	0.009	−0.017	0.008
Quintile 5	1.1	0.005	0.003	0.002	0.006	−0.014	0.001

Source: Authors' calculation based on the results from the Zambian CGE model.

The results from the modelling exercise show that bioethanol production (with no land displacement) does not negatively affect food security on aggregate and for the representative household groups presented here. Some individual households may be more negatively affected than reflected here; however, such an assessment is beyond the scope of this model. In rural households, consumption of both agricultural and processed foods increases, whereas in urban households processed foods are preferred to agricultural crops.

Total rural household food consumption, not presented here, increases by between 0.1 and 0.9 per cent by 2025 relative to the baseline scenario. Food consumption increases are largest under scenarios with the largest welfare gains. While rural consumption of agricultural food increases, there is a shift to processed foods, which become a larger share of total food consumption baskets. Food remains the largest commodity consumed by urban households. Under the sugarcane scenario (i.e. Scenario 1), consumption of agriculture food crops declines by less than 0.05 per cent by 2025 while processed food and poultry and fish consumption increases. Food consumption decreases marginally (less than 0.5 per cent) under cassava- and sweet sorghum-based bioethanol production (i.e. Scenarios 4 and 6) as higher food prices cause a shift in household consumption to non-food manufacturing commodities.

4.4 Releasing the constraint of unskilled labour

In addition to the scenarios considered above, we also assess the impact on the Zambian economy if sufficient unskilled labour is available to meet the increase in demand. The release of the unskilled labour constraint results in larger GDP gains, as average wage increases in the economy are partly offset by the increase in labour supply. Average annual real GDP growth is between 0.04 and 0.07 percentage points higher relative to the baseline scenario. Relative to the labour-constrained scenarios, average annual real GDP growth is about 0.02 percentage points higher across scenarios. Welfare gains are also larger. The direct and indirect impact of the bioethanol industry results in an increase in average annual employment growth of between 0.02 and 0.06 percentage points. As expected, the bulk of jobs are created in the bioethanol industry, although employment in food crop production and services also increases. The mining sector continues to experience a loss in employment due to the stronger exchange rate, which makes mining commodities less competitive. Under Scenario 1, manufacturing employment also decreases, although by less than before, as manufacturing sub-sectors—in particular the machinery and metals sub-sectors—become more capital intensive (see Table 10).

Table 10: Economic impacts under unconstrained low-skilled labour

	Deviation from baseline growth rate (%-pt)					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Sugarcane, status quo	Sugarcane, 20–80	Sugarcane and co-generation	Cassava	Cassava and displacement	Sweet sorghum
Total GDP	0.041	0.042	0.069	0.068	0.033	0.060
Agriculture	0.187	0.184	0.195	0.270	0.185	0.279
Mining	−0.276	−0.286	−0.176	−0.430	−0.417	−0.348
Manufacturing	0.111	0.104	0.398	0.213	0.169	0.130
Utilities and Construction	0.005	0.009	−0.017	0.050	0.039	0.016
Services	0.014	0.018	0.013	0.013	−0.014	0.017
Total employment	0.017	0.034	0.017	0.043	0.040	0.063
Agriculture	0.131	0.200	0.143	0.238	0.366	0.370
Mining	−0.736	−0.759	−0.479	−1.141	−1.098	−0.930
Manufacturing	−0.029	−0.014	−0.028	0.016	−0.068	0.029
Utilities and construction	−0.005	0.002	−0.035	0.057	0.045	0.008
Services	0.011	0.016	0.010	0.007	−0.024	0.013
Welfare						

Rural	0.028	0.042	0.018	0.130	0.037	0.115
Urban	0.015	0.022	0.010	0.030	0.008	0.038

Source: Authors' calculations based on the results from the Zambia CGE model.

5 Conclusions and recommendations

Biofuel production has the potential to help low-income, land-abundant countries meet their development goals of reducing poverty. Fully understanding the trade-offs and unintended consequences related to biofuel production is essential to developing a conducive environment and appropriate set of policies to ensure that positive returns from such a venture materialize. Developing a biofuel market in Southern Africa would have positive economic impacts for the region as it would strengthen trade links between Southern African countries. In this paper, we assessed the economic and welfare implications of introducing a bioethanol production industry in Zambia. We use a dynamic computable general equilibrium model for the country and consider alternative feedstock crops, farming scales, and potential constraints from land, labour, and capital.

Introducing biofuel production in Zambia has a positive impact on real GDP growth regardless of the feedstock crop used. Coupling bioethanol production with co-generation has the potential to double these positive impacts. Welfare increases across household groups in both rural and urban areas. This, coupled with general increases in food consumption, suggests that the introduction of a bioethanol industry in Zambia may not affect household food security. These results are, however, for representative household groups in the model; some individual households may be more negatively affected than reflected here. Food prices do increase because of increased demand for resources, and a general shift to processed foods does occur.

The result above is, however, dependent on the assumption that land displacement does not occur. Land displacement (see Scenario 5) has the potential to reduce economic gains from bioethanol production—although the overall impact remains positive,—and results in lower household welfare, signalling a potential concern for food security. If the full employment assumption for low-skilled labour categories is relaxed, which is highly realistic in a country such as Zambia, the impacts of bioethanol production on both economic growth and welfare are positive even with land displacement (see Section 0). The bioethanol industry could generate between 55,000 and 270,000 jobs, with the bulk arising from feedstock production. Additional jobs are created through knock-on impacts, although these are limited as some sectors become more capital intensive.

Given the feedstock and production costs set out in this paper, sweet sorghum is likely to be the most internationally competitive source of bioethanol production. However, cassava-based ethanol production, which is costed at US$0.023/L more than sorghum-based production, results in the highest returns to economic growth and welfare. Sugarcane-based ethanol has the potential to provide larger economic benefits than the other crops considered if production of ethanol is coupled with co-generation. The choice of feedstock, while dependent on cost-effectiveness, will also be determined by security of supply, which has been one of the key reasons for poor performance in the biofuels sector in the past (Samboko et al. 2017a, forthcoming).

The results in this paper outline the potential benefits from bioethanol production in Zambia. These benefits, however, can only be achieved if appropriate frameworks and systems are put in place that ensure the efficient functioning of the bioethanol market and shifting of production factors. Constraints or bottlenecks in the value chain will add to the costs of ethanol production and may negate the positive impacts presented here.

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