Bio-energy trade and regional development: the case of bio-ethanol in southern Africa

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This paper analyses the prospects for international bio-energy trade within the context of regional integration and sustainable development in the region of southern Africa, focusing on the particular case of bio-ethanol made from sugar cane and sweet sorghum. A number of options are considered for expanded production of and trade in bio-ethanol as a transport fuel for blending with petrol. The implications for alternative development paths and regional cooperation strategies are discussed and compared. Transportation costs appear to be small compared to production costs, although the higher cost of shipment by land implies a need for regional coordination strategies. The availability of suitable feedstocks in the region would have to increase significantly in order to achieve economies of scale. There appear to be valuable opportunities for creating new export markets, although international cooperation will be needed for reducing import tariffs and addressing non-tariff trade barriers as well as promoting technology transfer and capacity-building.

1. Introduction

Although biomass is the major source of energy in Sub-Saharan Africa, nearly all of this biomass is consumed in traditional uses in cooking, heating, and for small industries, in the form of fuel-wood, charcoal, and residues from agricultural and industrial production. The use of modern[1] bio-energy has generally been limited to those industries where residues are available on site as a result of the processing, such as timber mills and sugar factories, although conversion efficiencies have been fairly low. Some traditional forms of converted biomass, particularly charcoal, have also found export markets for use in industry. There have also been some limited uses of liquid biofuels for transport and gaseous biofuels for small-scale applications.

On average, biomass in tropical and sub-tropical climates is five times as productive, in terms of photosynthetic efficiency, as biomass produced in temperate regions [Bassam, 1998]. A recent study found that the bio-energy potential of Sub-Saharan Africa – after accounting for food production and resource constraints – was the greatest among all major world regions [Smeets et al., 2004]. The high potential results from the large areas of suitable cropland in the region, large areas of pasture land that are not currently used and the low productivity of existing agricultural production systems. In addition to the favourable physical conditions for biomass, the low cost of labour is another important factor that contributes to a comparative advantage for production of biomass and bio-energy in the region.

At the same time, much of Sub-Saharan Africa is characterised by severe poverty, low levels of investment, poor infrastructure, and the crippling socio-economic impacts of HIV/AIDS. Under such dire circumstances, the expansion of bio-energy may seem to have a low priority, and even if it is accorded a high priority, the lack of investment and infrastructure pose formidable obstacles outside of a few countries such as South Africa. However, when placed in the broader context of regional economic integration and sustainable development, the potential role for bio-energy becomes more attractive, since different countries in the region can mutually benefit from a pooling of their resources, joint utilisation of their comparative advantages in global markets, and better linkages among the physical and human elements of their infrastructure.

A large region that is undergoing a process of economic integration – the Southern African Development Community (SADC) – is therefore of special interest. SADC is aiming at not only a free trade zone, but also a higher level of political cooperation and economic coordination in utilising its resources for the benefit of the whole region [SADC, 2005]. The creation of rural-based industries such as those associated with biomass and bio-energy is especially appealing for a region that is predominantly rural. The comparative advantage of the region in combination with the need for greater investment and hard currency earnings suggests opportunities for new export markets in the emerging global trade in biomass and bio-energy products.

This broader regional economic context has become

Table 1. Land use summary for SADC countries and other selected countries

Country/region	Total land area	Forest area		Agricultural area[1]		Cultivated area[2]	
Units	**Million ha (Mha)**	**Mha**	**Share of total land area (%)**	**Mha**	**Share of total land area (%)**	**Mha**	**Share of total land area (%)**
Angola	124.7	69.8	56	57.6	46	3.6	2.9
Botswana	56.7	12.4	22	26.0	46	0.4	0.7
Congo	226.7	135.2	60	22.8	10	7.8	3.4
Lesotho	3.0			2.3	77	0.3	11.0
Madagascar	58.2	11.7	20	27.6	47	3.6	6.1
Malawi	9.4	2.6	27	4.4	47	2.6	27.5
Mauritius	0.2			0.1	56	0.1	52.2
Mozambique	78.4	30.6	39	48.6	62	4.6	5.8
Namibia	82.3	8.0	10	38.8	47	0.8	1.0
South Africa	121.4	8.9	7	99.6	82	15.7	12.9
Swaziland	1.7			1.4	81	0.2	11.2
Tanzania	88.4	38.8	44	48.1	54	5.1	5.8
Zambia	74.3	31.2	42	35.3	47	5.3	7.1
Zimbabwe	38.7	19.0	49	20.6	53	3.4	8.7
Total SADC	**964.1**	**368.3**	**38**	**433.2**	**45**	**53.4**	**5.5**
Brazil	845.9	543.9	64	263.6	31	66.6	7.9
China	932.7	163.5	18	554.9	59	154.9	16.6
India	297.3	64.1	22	180.8	61	169.7	57.1
United States	915.9	226.0	25	409.3	45	175.5	19.2

Sources: FAOSTAT, 2005; WRI, 2005

Notes

1. Agricultural areas include temporary and permanent pastures, and areas under permanent crops and temporary crops. The figures do not provide any indication of the suitability or availability of the land for particular purposes.
2. Cultivated areas includes areas under permanent crops and temporary crops.

more important with the recent rise in oil prices, since most of the countries of the region depend significantly on energy imports. The process of economic integration in SADC could potentially facilitate – and benefit from – the expanded production of modern biomass and biofuels. The domestic benefits will include health improvements, reduced regional emissions, and creation of rural livelihoods. The macroeconomic impacts include foreign exchange savings and reduced dependence on imported sources of energy. There is also significant potential for greenhouse gas (GHG) emission reductions from expanded use of modern bio-energy, with the latter potentially earning credits under the Kyoto Protocol's Clean Development Mechanism (CDM).

The case of bio-ethanol is of special interest for Southern Africa due to the long experience with sugar cane in the region and the impact of recent competitive pressures that have increased economic incentives for sugar producers to diversify into bio-energy and other areas. Historically, market distortions in the form of subsidies and preferential market access have slowed the process of diversification. With those supports now being gradually phased out, sugar producers who wish to remain competitive, or indeed stay in business at all, will need to look at renewable energy production on a much larger scale. The possibility of developing an export market for bio-ethanol from the region arises from the increased demand for biofuels in OECD countries and the comparative advantages of SADC countries [DSD, 2005; Lichts, 2006].

2. Regional overview

SADC was created in 1992 and currently includes fourteen member states[2]. Its objectives include regional integration, peace and security, maximising productive employment, promoting economic development, and achieving sustainable utilisation of natural resources. In many respects, these objectives are similar to those of other economic blocs around the world, such as the European Union (EU). In the case of SADC there is a special emphasis on food security, poverty alleviation and addressing major health threats, particularly HIV/AIDS.

As shown in Table 1, the SADC region encompasses a sizable area, larger than Brazil, China, or the USA and more than three times the size of India. It has a considerable amount of forested lands, nearly as much as the USA and China combined. The region has an even greater amount of pasture, grassland, and other areas that fall under the agricultural heading. It does have some arid and semi-arid areas where agriculture is highly limited; however, it does not have significant mountain ranges that

Table 2. GDP, population, and energy indicators for selected SADC and other countries, 2002-2004

Country/region	GDP/capita (US$)		Population			Energy indicators		
Units	Nominal GDP	GDP - PPP[1]	1000s	Density (persons/km^2)	Agricultural population (%)[2]	TPES/GDP (kJ/US$)	TPES/GDP - PPP (kJ/US$ PPP)	TPES/cap (MJ/cap)[3]
Angola	1304	2457	13625	11	71	7539	4001	9831
Botswana	5702	10169	1785	3	44	5286	2964	30141
Congo	111	633	52771	23	62	14294	2506	1587
Lesotho	633	2074	1802	59	39	5769	1761	3652
Madagascar	251	854	17404	30	73	8678	2551	2178
Malawi	152	569	12105	129	76	13275	3546	2018
Mauritius	4833	12215	1221	601	10	9349	3699	45185
Mozambique	320	1247	18863	24	76	23277	5973	7448
Namibia	2233	6449	1987	2	47	11686	4046	26095
South Africa	4587	10798	45026	37	13	23879	10144	109533
Swaziland	2172	4995	1077	63	32	9478	4122	20587
Tanzania	308	673	36977	42	77	6822	3122	2101
Zambia	478	870	10812	15	68	22507	12366	10758
Zimbabwe	491	2309	12891	33	61	31699	6741	15564
Total SADC	**1267**	**3142**	**228346**	**24**	**57**	**20522**	**8275**	**25998**
Brazil	3325	8049	178470	21	15	15368	6348	51099
China	1272	5642	1311709	141	65	27080	6105	34446
India	622	3080	1065462	358	52	22114	4466	13755
United States	39935	39496	294043	32	2	8789	8886	350973
EU-15	29291	26900	380051	121	4	6402	6473	163696

Sources: FAOSTAT, 2005; World Bank, 2005; IEA, 2004

Notes

1. PPP = Purchasing power parity, which reflects better differences in cost of living, whereas nominal GDP accounts more appropriately for the value of international trade
2. Agricultural population comprises those persons who earn their livelihood from agricultural activities along with their non-working dependents.
3. TPES = Total primary energy suppy (consumption).

render major areas uninhabitable (such as China does). The present amount of land cultivated is quite small – less than 6 % – the comparable figures elsewhere in the world being generally much higher. These aggregate figures do not necessarily indicate anything about the land available for expanded agricultural or biomass production, since many other characteristics have to be considered. However, it does provide some indication of the scale of land resources and current utilisation.

In economic terms, several countries in the region are among the poorest in the world, with per capita incomes less than a dollar per day. The lower cost of living in these countries relative to global conditions offsets this income poverty to a degree. Purchasing power parity (PPP) GDP is thus generally several times higher than nominal GDP. In general, the poorer countries in SADC also have a higher proportion of the population working in agriculture. The large share of the population that lives in rural areas and relies on the agricultural sector represents a large potential labour force for expanding the production of biomass and bio-energy. The population density is fairly low by global standards, although with considerable variation. In general, the region appears to have a significant amount of natural and human capital that is underutilised.

With the exception of South Africa, per capita energy consumption is low by world standards, as given in Table 2. However, energy consumption relative to GDP is quite high, due in part to the dominance of low-value-added and/or resource-intensive industries in many countries in the region. The rural population and the peri-urban population generally do not have grid access and rely on traditional uses of biomass, mainly fuel-wood and charcoal. A number of small-scale industries rely on agricultural and forest residues. In the transport sector, consumption of diesel exceeds that of petrol, due to the heavy reliance on freight shipment by road (rather than rail). It is one of the few regions in the world where leaded fuel is still widely used; consequently, the expanded use of bio-ethanol blends would have significant health benefits in replacing lead as an octane enhancer [Thomas and Kwong, 2001].

Charcoal production, sale and distribution is a major source of livelihood in rural and peri-urban areas. Contrary to popular belief, in many areas the use of charcoal has not yet exceeded levels at which it can be characterized as sustainable, and is not a major contributor to deforestation [Chidumayo, 2002]. The price of charcoal is generally relatively stable, regardless of the distance transported, i.e., it is a regional commodity in many respects [Ellegård et al., 2002], although cross-border trade is difficult due to taxes and controls. South Africa and Madagascar also have a sizable international export market for charcoal. Household use of fuel-wood and charcoal have a number of impacts on health; cleaner renewable fuels, such as gelfuel made from bio-ethanol, have been proposed as a solution that takes advantage of the region's underutilised agricultural capacity [Utria, 2004].

Another possibility that is being explored in the region for expanding modern bio-energy is the use of bio-diesel produced from oil-bearing crops such as jatropha or palm oil. The possibility for small-scale dispersed production[3] in combination with the high level of diesel consumption in relation to petrol could make this an attractive option. However, bio-diesel is not yet cost-competitive with diesel, whereas bio-ethanol appears to have greater near-term potential, in comparison to bio-diesel, to be cost-competitive in a region such as Southern Africa. Furthermore, the comparative advantage for bio-diesel in the region would not be as significant as it is for bio-ethanol, and consequently bio-diesel is less likely to find export markets.

3. Sugar cane and bio-ethanol

Among the major agricultural crops in the region that are of interest for their biomass potential are maize, sorghum, cassava, sugar cane, and wheat. Bio-ethanol has been produced from sugar cane on an industrial scale (i.e., beyond local use) in the region since the late 1970s. Analyses of longer-term prospects for bio-ethanol have tended to focus on sweet sorghum, a variety of sorghum optimised for fermentable sugars that has a number of climatic advantages in comparison to other alternatives [Woods, 2001]. Some scenarios for major future expansion have focused on the cooking market, in which ethanol – made from maize, sugar cane, sweet sorghum, cassava, and sweet potatoes – would be used to make gelfuel that would substitute for fuel-wood or charcoal [Utria, 2004]. A market of 10 billion litres (Gl) is envisaged in the analysis, enough to substitute for 30 % of all cooking fuel in Sub-Saharan Africa.

Since this analysis is focused more on the potential for export markets, the market for cooking fuels is not considered here, and instead the focus is on the transport sector, where the export demand would have its highest volume[4]. It is useful to note, however, that creating a high-volume market of 10 Gl is difficult in the household sector due to the transaction costs associated with millions of households switching from traditional cooking methods to using gelfuel. A more plausible scenario would seem to be an ethanol market that is built up by volume based on demand in the transport sector, including exports. Unlike the household sector, the transport sector would create demand that is more centralized, albeit dependent on policy support from national governments. The household market would then benefit from the wider distribution and economies of scale that can only emerge at high market volumes.

Sugar cane is the feedstock for bio-ethanol that currently has the best energy balance and lowest production cost, particularly in Brazil, but also in most areas where it can be economically grown. This is due primarily to the high photosynthetic efficiency of the sugar cane, *Saccharum officinarum,* a perennial grass whose cultivation is limited by plant physiology to tropical and sub-tropical regions. The sugar cane stalks contain the cane juice from which sucrose is extracted and/or bio-ethanol is produced, and they are shipped to the sugar factory by truck or rail, marking the end of the agricultural stage and the start of the industrial stage of sugar-cane processing.

Most sugar factories are integrated with nearby fields because the sucrose content is rapidly depleted in cut cane stalks and the time between harvest and processing at the factory must be minimized for maximum yield. Sugar production at the factory is perhaps best viewed not as a manufacturing process but as a series of liquid-solid separations to isolate the sucrose [Blume, 1985]. The process of extraction includes shredding the cane and crushing it through several horizontal rollers to extract the juice, leaving the fibrous residue known as bagasse. The juice from the milling station is an acidic greenish liquid that contains impurities such as soil, protein, fats, waxes, gums, fine bagasse, and soluble salts [Moroz and Broeg, 1992]. Subsequent steps are aimed at purification and concentration of the juice, followed by centrifugation to crystallize the sucrose by separating it from the mother liquor.

For bio-ethanol production from cane juice, only juice purification steps are needed, whereas if both bio-ethanol and sugar are to be produced, then the sugar factory with all its additional processing steps is needed, including several rounds of centrifuging, which yields final molasses (blackstrap) and a viscous sugar (syrup) that is fed back to enhance crystallization. Bio-ethanol can be made from the final molasses (C-molasses), from either of the previous two production stages (B-molasses and A-molasses) or from the cane juice, or in fact any mixture of them. In Brazil, it is common to use a mixture of cane juice and B-molasses [Macedo, 2005]. The output of the sugar factory is a brown granulated sugar known as "raw sugar" with a sucrose content varying from 94 to 99 %.

When sugar prices are high, other things being equal, a producer that is capable of making both sugar and ethanol (i.e., there is a sugar factory and an ethanol distillery) will prefer to use only C-molasses as feedstock for ethanol, because the extraction of sucrose from the sugar cane is to be maximised. When sugar prices are low, the producer will prefer to use higher grades of feedstock (i.e. A- and B-molasses and cane juice) as they contain more fermentable sugars, thereby increasing the yield of ethanol production. There are thus opportunity costs involved in the calculations of a sugar producer who also makes ethanol. Brazil is effectively the only swing producer in this type of market, due to its volume and efficiency and the fact that most producers make both and can shift away from

Table 3. Sugar cane production in 2004 in SADC and selected other countries

	Area harvested	Total production	Average yield	Shares of total production	
	1000 ha	1000 tonnes cane (tc)	tc/ha	Share of SADC total (%)	Share of world total (%)
Angola	10	360	38	0.8	
DR Congo	43	1786	42	3.9	
Madagascar	69	2460	36	5.4	
Malawi	20	2100	105	4.6	
Mauritius	72	5199	73	11.4	
Mozambique	30	400	13	0.9	
South Africa	326	20419	63	44.8	1.5
Swaziland	48	4500	93	9.9	
Tanzania	17	2000	118	4.4	
Zambia	17	1800	106	4.0	
Zimbabwe	45	4533	101	10.0	
SADC total	**696**	**45557**	**65**		**3.4**
Australia	448	36995	83		2.7
Brazil	5371	396012	74		29.1
India	4608	281600	61		20.7
Thailand	1139	74259	65		5.5
World	**20822**	**1359120**	**65**		

Source: FAOSTAT, 2005

one product to the other fairly easily.

Although sugar cane is currently the most efficient crop for bio-ethanol in production terms, the use of several different feedstocks is one way to hedge against the risks of lower future prices for other crops and thereby help to stabilise agricultural markets. In South Africa, maize is seen as an important feedstock for bio-ethanol expansion because of its significant surplus in maize production, and ethanol plants using maize are currently under construction [Ethanol Africa, 2006].

Bio-ethanol from maize has a much worse energy balance and thus does not have the environmental benefits of cane-based ethanol. Credits for carbon emission reductions would therefore be considerably less in the case of corn (maize)-based ethanol. Indeed, in some cases, where the factory is fired from coal-based sources, the energy balance and carbon balance can even be negative compared to petrol [Farrell et al., 2006]. For export markets, the most efficient feedstocks are needed and consequently sugar cane and sweet sorghum would be preferred in the near term, other things being equal.

4. Sugar cane and sugar in Southern Africa

Production of sugar cane in SADC is small in global terms, whereas India and Brazil together account for half of the world total (see Table 3). India produces sugar for the domestic market, whereas Brazil is a major exporter of both sugar and bio-ethanol. Production of sugar cane in the SADC region is dominated by South Africa, Mauritius, and Zimbabwe, which together account for more than 65 % of the SADC total. Some countries have factories that are in very poor condition due to years of unrest and/or lack of investment, including Angola, the Democratic Republic of Congo (DR Congo), Madagascar, and Mozambique. It is interesting to note that the SADC average yield is almost identical to the world average, although this is due to the low average yields in South Africa. A number of producers have traditionally had very high yields, particularly those in Malawi, Zambia, and Zimbabwe, while in Tanzania recent investment has helped to improve their yields considerably.

The high yields are primarily due to the excellent climatic conditions in certain regions in these countries, although in some cases yields have also been boosted through irrigation and other resource inputs. The use of water for irrigation and in the factory is higher than in Brazil, where there is very little irrigation and 90 % of water used in the factory is recycled [Macedo, 2005]. Water conservation will be increasingly important in the future, as some areas may face water scarcity, and therefore new sugar cane areas should be sited in regions with sufficient rainfall to avoid the need for irrigation. According to GIS analysis, most areas with sufficient rainfall that are not already under sugar cane appear to be located in Zambia, Malawi, Tanzania, and Mozambique [Watson et al., 2006].

Many producers in the region are indeed cost-competitive by world standards, reflecting excellent growing conditions for sugar cane and efficient milling operations, but not all have been able to exploit their full potential. In the past, regional conflicts resulted in the collapse of some industries (Mozambique, now under rehabilitation) and at the same time hampered the ability of land-locked countries (Malawi, Swaziland, Zambia, Zimbabwe) to get

Table 4. SADC sugar production, consumption, preferential markets; 2001-03 average (thousand tonnes)

	Production	Consumption	Preferential exports					Net total of imports & other exports
			EU sugar protocol	EU SPS[1]	EU EBA[1]	US quota	Total	
Botswana	0.0	47.0	0.0	0.0	0.0	0.0	0.0	(47.0)
Namibia	0.0	48.3	0.0	0.0	0.0	0.0	0.0	(48.3)
South Africa	2498.5	1418.2	0.0	0.0	0.0	24.2	24.2	1056.0
Swaziland	619.3	107.8	139.1	32.5	0.0	16.9	188.4	323.0
SACU[2]	**3171.7**	**1621.4**	**139.1**	**32.5**	**0.0**	**41.1**	**212.7**	**1283.7**
Angola	0.0	178.3	0.0	0.0	0.0	0.0	0.0	(178.3)
DR Congo	63.3	85.0	0.0	0.0	0.0	0.0	0.0	(21.7)
Malawi	240.9	145.0	25.0	10.8	10.7	10.5	57.0	49.6
Mauritius	591.9	42.5	580.4	33.1	0.0	12.6	626.1	(76.7)
Mozambique	151.7	108.3	0.0	0.0	9.7	13.7	23.4	19.9
Tanzania	173.0	194.3	11.9	2.4	10.3	0.0	24.6	(46.0)
Zambia	220.6	107.4	0.0	13.7	9.9	0.0	23.6	89.6
Zimbabwe	531.9	318.5	35.9	27.9	0.0	12.6	76.4	137.1
Non-SACU	1973.4	1182.3	653.3	87.9	40.5	49.5	831.1	(40.1)
SADC	5091.1	2800.7	792.4	120.3	40.5	90.6	1044	1246.6

Source: International Sugar Organisation (ISO) Statistics 2004

Notes

1. SPS = Special Preferential Sugar; EBA = Everything but Arms Initiative
2. The South African Customs Union (SACU) is based on a revenue-sharing customs union between Botswana, Lesotho, Namibia, South Africa and Swaziland.

access to the world market. Furthermore, sugar prices have been highly distorted and complicated by the various special trading arrangements and preferred markets (see Table 4). The EU and USA have long subsidised their own domestic producers, but they have also provided preferential access to certain developing countries. Recent trade agreements and reforms are gradually reducing and, in some cases, removing such supports, in order to achieve WTO compliance [ISJ, 2006].

The average annual production during 2001-2003 was slightly over 5 million tonnes (Mt). Sugar production in the region continues to show steady growth at a rate of 2.5 % per annum, which is mainly due to rehabilitation programmes being undertaken in the sugar sector in countries such as Tanzania and Mozambique. Although the total production in SADC is not big in world terms, the sugar industry represents an important sector in some of the economies of the region.

About 2.29 Mt were destined for export, out of which about 45 % had access to the higher-priced preferential markets and the rest was sold to the world market. As with most of the sugar sold around the world, a preferential price is applied to many SADC producers under agreements with the EU and in association with the African, Caribbean, and Pacific (ACP) group of countries. The preferential prices are sometimes as much as 2-3 times the international market price. For the SADC countries, these preferential markets effectively balance out any losses due to sales on the open market. Some producers even sell beyond their own consumption needs, and then import sugar at the lower world market prices. The many years of distorted sugar markets have also had the effect of discouraging the expansion of bio-ethanol and other co-products[5].

The sugar industries of the region face new challenges and opportunities over the coming decade. These include:

- closer economic integration in SADC;
- reform of EU sugar policy, which governs preferential prices for SADC sales to the EU;
- commitments to the World Trade Organization under the Doha Round of negotiations; and
- pressures for greater smallholder participation and land reform.

The way producers respond to these issues will be crucial in determining whether the region will be able to exploit its full potential. At the same time, outcomes relating to these issues will also create significant new incentives for market diversification and will become a substantial driver for fuel ethanol production. A major challenge will be to reduce the cost of ethanol production to levels that are competitive on the global market.

Another major condition for the growth of a regional bio-ethanol industry is the continued process of economic integration in SADC, including eventual elimination of import tariffs and harmonisation of standards and certification processes that affect the terms of trade. Many countries in the region continue to protect certain industries and a number of regulations are based on the local added value of products so as to prevent re-export of goods purchased at lower international prices. Furthermore, some OECD countries still place tariffs on a number of renewable energy products and services, including biofuels and various renewable energy

Table 5. Ethanol production cost estimates (US$/litre), selected locations and feedstocks

Location	Sugar factory capacity (tc/day)	Ethanol distillery capacity (kl/day)	Cost (low estimate)	Cost (high estimate)
Brazil (Centre- South)	500	1000	0.19	0.25
Malawi (existing)	166	Not given	0.50	0.60
Zambia (new)	300	100	0.35	0.45
Zimbabwe (existing)	484	Not given	0.25	0.40

Sources: Chanje, 1999; Cornland et al., 2001; Macedo, 2005; Wenman, 1999

conversion devices [Steenblik, 2005].

The previous proliferation of preferential markets and the continuing existence and potential for bilateral agreements between different trading zones may have implications for the ability of SADC countries to expand exports within the region as against expanding external (i.e., out of the region) exports. It is generally assumed that the economic integration process in SADC will lead to expansion of trade within the region that is dominated by trade between South Africa and the rest of SADC. However, one study using a computable general equilibrium (CGE) model found that producers in SADC will tend to sell to the EU market rather than to South Africa, and the result is that for some products, intra-regional trade is not necessarily preferable to trade with the EU [Lewis et al., 2001].

It is difficult to generalise from a set of point estimates of ethanol production costs outside of the highly developed industry found in Brazil, mainly because the cost of ethanol production is still closely related to the value (opportunity cost) of forgone sugar production, which is quite high under the current preferential pricing arrangements. In South Africa, mill extraction is quite high, and this higher efficiency in sugar production translates into a lower quality feedstock for ethanol, as the molasses used for ethanol has lower sugar content. A market that incorporates production of both ethanol and sugar, as in Brazil, would induce different technical configurations at the factories, which involves further costs in the case of existing factories. As preferential sugar markets decrease in the coming years, sugar producers will have greater incentives to defer sugar production in favour of bio-ethanol. One recent study using a CGE model also showed that SADC countries fared best under agreements with the EU and with multilateral agreements and fared worst when major trading regions such as the EU and MERCOSUR (Latin America) established bilateral trade agreements [Keck and Piermartini, 2005]. This suggests that a strategy including bio-ethanol exports to the EU may be more beneficial than a strategy based only on intra-regional markets for bio-ethanol, due to the higher comparative advantages gained through trade with the EU.

5. Production, transport, and impacts of bio-ethanol

There is already some experience in the region with bio-ethanol production, particularly in Malawi and Zimbabwe, both of which have experience in blending ethanol. Zimbabwe began its programme in 1980 and blended ethanol with petrol until 1992, when a severe drought drove production of both sugar and ethanol to nearly zero [Wenman, 1999]. A lack of government support in combination with the creation of export markets in Europe for potable ethanol (ethanol for beverages) resulted in an end to the blending programme. The recent government decision to phase out leaded petrol could potentially revive it [Herald, 2006]. In Malawi, ethanol production began in 1982 and has continued uninterrupted, although the production volumes have fluctuated significantly over the years [Kartha et al., 2005]. South Africa has been producing synthetic ethanol from coal for the industrial market.

The direct costs associated with delivering bio-ethanol to end-users include feedstock costs, production costs, and transport costs. Feedstock costs vary according to the biomass source, such as corn (maize), wheat, sugar cane, or sugar beet. Production costs include the costs due to energy, capital, labour, administration, and other resources, and vary with the process and the particular technology configuration. The choice of process and technology will generally be optimised for the primary feedstock to be used, although in some cases more than one feedstock can be used (e.g., in the case of sugar cane, molasses or cane juice can be used) without significant impact on technical efficiency. Transport costs are those associated with shipment by rail, road, pipeline, and/or sea.

Another category to consider relates to co-product credits, which should be valued positively against the costs in order to carry out a proper accounting. Such credits are especially needed in the case of sugar cane, since there are often several different co-products used internally and/or sold on external markets. The co-products often include fertilisers, animal feeds, co-generated electricity from bagasse and field residues, and a variety of downstream products that depend on such factors as regional infrastructure and proximity to major population centres, as well as general market conditions. Co-product credits are highly site-specific, however, and they are therefore not included in this analysis.

In practice, it is often quite difficult to separate feedstock costs from processing costs, given the relationship between feedstocks, intermediate products, and choice of conversion technologies. The choice of a particular feedstock depends on its value in alternative uses and on the value of co-products; furthermore, the value of feedstock is often determined endogenously (i.e., the choices of individual ethanol producers in a given market impact the prices of their own feedstocks). Consequently, these costs are often combined into a single average cost estimate per unit of output. Table 5 shows some estimates of production costs for various feedstocks in various locations and based on either existing or new (future) factories. The high cost in Malawi is partly attributable to the small size of the factory[6].

Transportation costs by sea can be estimated from distances and a number of assumptions concerning the tanker capacity, speed and related characteristics. Table 6 gives the distances between selected international ports and selected ports in the SADC region, and Table 7 gives the cost estimates. The costs are fairly modest compared with production costs, amounting generally to less than 10 % of the production costs. The estimates are based on a tanker that can traverse the Panama and Suez canals.

Road transport costs are estimated similarly using assumptions about a typical truck tanker and the costs of fuel and other operating costs. Table 8 gives selected distances and Table 9 gives the estimated road transport costs. The road transport costs are generally several times the cost of shipment by sea. Table 10 gives the total estimated costs for exported ethanol arriving at selected ports, in comparison with retail petrol prices in the broader geographical regions that might be served through those ports. The margins between low and high estimates provide some sense of the scope for policy initiatives (e.g. reduced tariffs, tax rebates) to promote bio-ethanol trade. In the U.S., where retail prices are low, the margins are tight, whereas in the EU, there is ample opportunity to promote bio-ethanol trade. It is harder to generalise about Asian or South American markets due to their high variation.

Import tariffs in some OECD as well as SADC countries could affect the trade in bio-ethanol. There are also non-tariff barriers, particularly standards, which could block trade by creating a technical requirement relating to chemical content or feedstock, such that the standard cannot be met by imports. In the case of exports to OECD countries, the question also arises whether bio-ethanol could receive credits for GHG reductions and thereby help to defray the additional cost due to transport and tariffs. A similar question arises as to whether these GHG reductions are significantly greater than GHG reductions from bio-ethanol produced in OECD countries. Table 11 gives tariffs in comparison to petrol prices. The CO_2 credits would be small and would generally not provide sufficient incentives although they would offset transportation costs. Import tariffs in some cases are a significant share of the effective price. The main point is that import tariffs are generally a much higher barrier to trade than transport costs.

In order to make a first-order estimate of the scale economies needed for bio-ethanol production and export in the region, data from nearly all of the sugar factories in the region were compiled, including the total cane processed per year and the capacity of the factory (tonnes cane/hour or tc/hr). Table 12 shows the figures and an estimate of bio-ethanol production by feedstock.

The investment cost for a new sugar factory and an annexed distillery is of the order of US$ 75 million [Leal, 2005] with most of the cost for the factory. Construction of a new sugar factory also takes much more time than construction of an ethanol distillery. Consequently, it seems likely that any expansion in the SADC region would occur primarily through existing factories. The minimum efficient scale (MES) of feedstock for bio-ethanol production has been estimated in Brazil as 2 Mt cane (Mtc) per year, with the daily capacity depending somewhat

Table 6. Distances between selected international and SADC ports (km)

From/to	Durban	Saldanha Bay	Maputo	Dar-es-Salaam
Rotterdam (Netherlands)	12860	11321	13405	11855
Los Angeles (USA)	20113	18737	20657	21687
Singapore	9014	10484	8819	7484
Santos (Brazil)	7699	6289	8244	10605

Source: www.distances.com

Table 7. Estimated shipping costs (US$/kl) between selected international and SADC ports

Port/city	Durban	Saldanha Bay	Maputo	Dar-es-Salaam
Rotterdam (Netherlands)	9	8	9	8
Los Angeles (USA)	14	13	14	15
Singapore	6	7	6	5
Santos (Brazil)	5	5	6	7

Assumptions: based on a tanker with 50,000 t net deadweight capacity travelling at 15 knots (about 28 km/hr) along the estimated port distances (www.distances.com) and using assumptions in [Hamelinck et al., 2003]

Table 8. Estimated road distances (km) between selected inland cities and ports

From/to	Durban	Saldanha Bay	Maputo	Dar-es-Salaam
Johannesburg	557	1498	555	3757
Harare	1711	2671	1464	2634
Lilongwe	2678	3639	1933	1667
Lusaka	2381	3160	1950	1985

Source: MAPSTUDIO, 2002

Table 9. Estimated road transport costs (US$/kl) between selected inland cities and ports

From/to	Durban	Saldanha Bay	Maputo	Dar-es-Salaam
Johannesburg	10	26	9	64
Harare	29	46	25	45
Lilongwe	46	62	33	29
Lusaka	41	54	33	34

Assumptions: based on a tanker with 35,000 l capacity; fuel costs = 0.8 US$/l; other costs = 0.4 US$/km; tanker fuel (energy) consumption = 10 MJ/km

Table 10. Total estimated delivered costs of exported ethanol (net of profit margins, import tariffs, and distribution costs) and pump prices of motor gasoline in selected locations

Port location	Volumetric basis (US$/kl)		Energy basis (for blending) (US$/kl)		Regional[1] pump petrol prices (US$/kl)		Margin[2] (% of ethanol price, energy basis)	
	Low	High	Low	High	Low	High	Low	High
Rotterdam (Netherlands)	368	671	526	959	1140	1620	35	208
Los Angeles (USA)	272	398	389	569	540	680	-7	75
Singapore	331	503	473	719	480	1350	-50	185
Santos (Brazil)	265	452	379	646	500	1130	-38	198

Source for pump prices: Metschies, 2005

Assumptions: calculated based on min./max. costs for given location

Notes

1. Regions corresponding to the listed ports are EU, North America, Asia, South America
2. Low (high) margins based on high (low) production cost paired with low (high) pump price

Table 11. Average import tariffs and retail prices, regular unleaded petrol (US¢/l)

	Import tariff	Petrol price	Ethanol equivalent price[1]	Tariff as % of ethanol equivalent price
Australia	23	72	50	46
Canada	5	63	44	11
EU	10	138	97	10
Japan	0	104	73	0
USA	14	50	35	40

Sources: IEA, 2004; US-DOE/EIA, 2005

Note

1. Based on quantity of petrol substituted, assuming ethanol energy content = 70 % of that of petrol

on the length of the growing season. Only four of the 40 factories, as shown in Table 12, exceed this scale. In order to estimate the additional feedstock and production to achieve economies of scale, the difference between the amounts in the other 36 factories and the MES of 2 Mtc are summed. The additional feedstock amounts essentially to a doubling from the existing total for the region.

In addition to expansion of sugar cane, another possibility for bio-ethanol production is to choose another crop such as sweet sorghum, which might be dedicated to bio-ethanol production if there was high enough potential demand. Table 13 shows estimates of the available land in the region that was considered suitable or very suitable for sweet sorghum [Watson et al., 2006]. Sweet sorghum has a short growing cycle, generally between 4 and 5 months, and there could be two crop cycles per year, unlike sugar cane, which has a growing cycle of 12 months or longer.

In order to gauge a reasonable amount for world markets, it is useful to compare the total bio-ethanol that could be produced from sugarcane and sweet sorghum with other international markets, including the EU, US, China, and India. The EU biofuels directive aims to increase the share of biofuels to 5.75 % by 2010 and as much as 20% by 2020. The high cost of bio-ethanol production in Europe means that an import strategy would probably be more cost-effective in meeting this goal. Table 14 gives the potential production from sugar cane and sweet sorghum in comparison to international markets. Future year projections are made out to 2025 for demand using assumptions for growth in the different regions [US-DOE/EIA, 2005]. The areas for expansion are constrained to 25 % of the total suitable areas, in light of the relatively short time horizon.

The potential bio-ethanol available for export is fairly significant in terms of several key markets: Japan, China, and the EU-15. In geopolitical terms, the tremendous consumption in the US and the expected increases in consumption in China and elsewhere result in such high global demand for petrol that bio-ethanol also takes on strategic importance in terms of energy security. Nevertheless, it is clear that biofuels are only part of the solution for the soaring demand for petrol; demand-side measures will also be needed to bring the markets into better balance, but such issues are not considered in this analysis.

The land required for the expansion is shown in Table 15 and it turns out to be a fairly modest amount, about 1 % of the total agricultural land available and about 5 % of the land already under cultivation. It is important to note, however, that the fact that the land is suitable and/or available does not necessarily mean it is the most appropriate use of that land. A more detailed analysis would be required so as to consider a range of socio-economic and environmental factors together for different regions. Such analyses would further refine the estimates for land availability and feedstock production.

6. Discussion and conclusions

The exploitable bio-energy potential of the Sub-Saharan African region is significant. Economic integration in Southern Africa through SADC makes the Southern African region particularly appealing for bio-energy expansion, given the efforts at lowering trade barriers and the harmonization of standards and regulations in the SADC region. One area of bio-energy development that offers

Table 12. Feedstock supply and yield of sugar factories by size and additional feedstock potential

Factory characteristics and/or feedstock supply					Ethanol production (Ml) from		
Size category	**No. of factories**	**Average capacity (tc/hr)**	**Total produced Mtc/yr**	**Average production (Mtc/yr)**	**C-molasses**	**A/B-molasses**	**Cane juice**
2 Mtc/yr	4	469	9.244	2.311	83	185	693
1-2 Mtc/yr	16	305	23.064	1.538	208	461	1730
1 Mtc/yr	20	167	8.852	0.521	80	177	664
Total	40	258	41.159	1.143	370	823	3087
Additional cane as feedstock			40.085		361	802	3006
Total potential supply			81.244		731	1625	6093
Petrol equivalent					512	1137	4265

Sources for factory data: SMRI, 2004; MSRI, 2004

Note

Additional cane production is calculated as the sum of the amounts needed to bring all factories up to 2 Mtc/year; average yields for Cmolasses,- A/B-molasses, and cane juice are 9, 20, and 75 l/tc, respectively.

Table 13. Percentage of land area suitable for sweet sorghum in SADC countries

	Low inputs			High inputs		
	Unsuitable	**Somewhat suitable**	**Suitable**	**Unsuitable**	**Somewhat suitable**	**Suitable**
Angola	75.7	23.8	0.5	60.4	29.7	9.9
Malawi	50.2	38.6	11.2	41.3	33.0	25.7
Mozambique	42.8	40.8	16.4	25.8	46.5	27.7
South Africa	98.9	1.1	0.0	90.6	8.4	1.0
Swaziland	99.5	0.5	0.0	68.4	31.6	0.0
Tanzania	55.4	41.1	3.5	32.7	54.6	12.7
Zambia	32.6	59.8	7.6	16.5	50.0	33.5
Zimbabwe	79.4	20.4	0.2	40.4	56.2	3.4

Source: Watson et al., 2006

Note

Low and high inputs refer to the amount of fertilisers, land preparation, and other inputs.

some opportunities both for domestic markets and international markets is bio-ethanol. The region has a fairly strong industrial base in the sugar industry. Expansion of sugar production is unlikely to be rewarding, given decisions in recent years to reduce the preferential market access to ACP countries.

An analysis of possible future expansion in production of and trade in bio-ethanol reveals a number of key factors that will impact the market success of bio-ethanol for the region. First, the scale of production will have to be significantly greater, as the current factory sizes are too small to result in a large enough market for export to be competitive. Consequently, other sources of feedstock supply may be needed, and there will also be a need to coordinate feedstock supply and distribution channels so that the effective scale of production moves closer to where economies of scale are reached. The process of regional economic integration in SADC is thereby both a facilitator and a beneficiary of expanded bio-ethanol production.

Second, improvements to and capacity expansions of the distribution and transportation infrastructure in the region will be needed in order to facilitate significant expansions in trade. This is due to the smaller size of many ports in the region as well as the general problems with land routes due to the extent and quality of road networks. Furthermore, since land transport costs are much higher than shipment by sea (for exports) the siting of facilities will become important to reduce costs if an export market is to be created. It may be desirable to locate distilleries near ports and ship feedstock to the distilleries. Coordination among SADC partners will therefore become important to optimise production and market sectors. Implicit in these improvements and changes is the need to maintain and, in fact, accelerate the pace of economic integration within SADC, so that trade in allied industries is improved equally.

Third, import tariffs imposed by some countries would have to be lowered or eliminated, as they represent in some cases a significant portion of the overall costs. By contrast, transportation costs, once the infrastructure is improved, represent a fairly small share of total delivered cost of the product. Equivalently, the import tariffs could

Table 14. Bio-ethanol production potential from sugar cane and sweet sorghum (Ml)

Year	2005	2010	2015	2020	2025
SADC total (cane, existing areas)	939	1013	1085	1165	1252
SADC total (cane, new areas)	0	311	844	1882	3925
SADC total (all cane)	939	1324	1929	3047	5177
SADC total (sweet sorghum)	0	5119	11858	20603	31819
SADC total (all)	**939**	**6443**	**13787**	**23650**	**36996**
SADC demand and projections (energy basis)	**203**	**2475**	**4315**	**6155**	**8195**
Assumed percentage bio-ethanol (%)	1	10	15	20	25
Remaining allocation for export market	**736**	**3968**	**9472**	**17495**	**28801**
Relative to demand in other regions (volume basis, %)					
China	1	4	9	15	21
Japan	1	7	16	29	48
United States	0	1	2	3	4
EU-15	0	2	6	10	16

Sources: Demand projections from US-DOE/EIA, 2005

Assumptions: (1) internal SADC demand (increasing from 1 % to 25 % up to 2025) is met first before allocating to exports (2) ethanol yields: increasing from 75 to 90 l/tc between 2005 and 2025.

Table 15. Area required for bio-ethanol production from sugar cane and sweet sorghum (kha)

	Area under cane			Area under sweet sorghum		Total area under cane and sweet sorghum		Relative to available agricultural areas (%)	
Country/year	2010	2025	Average annual change (%)	2010	2025	2010	2025	Total available	Currently under cultivation
Malawi	23	39	4	66	263	89	302	2	4
Mozambique	55	269	12	804	3215	858	3484	2	23
South Africa	311	285	-1	0	0	311	285	0	2
Swaziland	43	42	0	0	0	43	42	3	22
Tanzania	19	29	3	193	773	213	802	0	4
Zambia	32	143	11	353	1412	385	1556	1	9
Zimbabwe	42	41	0	5	19	47	61	0	1
Other SADC	169	126	-2	39	156	208	282	0	1
Total SADC	**695**	**974**	**2**	**1460**	**5839**	**2155**	**6813**	**1**	**5**

Source for demand data and projections: US-DOE/EIA, 2005

Assumptions for cane: land under cane allocated to countries on basis of yield and availability (i.e., higher yield is preferred); yields increasing from 65 to 90 t/ha between 2005 and 2025.

Assumptions for sweet sorghum: land is allocated incrementally up to 25 % of land suitable by 2025; yields increasing from 40 to 60 t/ha between 2005 and 2025.

be lifted for developing countries that are to receive favourable markets – this is equivalent in some sense to other preferential markets, but it has a purpose beyond supporting old industries in that it promotes a domestic renewable resource for the region.

Fourth, some producers in the SADC region may have a preference for exports to international markets, particularly the EU, rather than intra-SADC trade, due to the commitments made in those countries for expanding bio-fuels. A reasonably assured market, potentially through long-term contracts, would be an important requirement for investment in the region. However, GHG credits do not appear to be a useful incentive for bio-ethanol expansion, unless carbon prices go up and/or if enough credit for co-products can be obtained to create additional value.

This analysis has been quite aggregate and only provides a first-order estimation that significant expansion in production and export of bio-ethanol appears to be feasible. The main point to be emphasised is that synergies between an export strategy and regional development strategies could emerge that make the overall expansion more attractive. More detailed analysis of the economic parameters for expanded utilisation of the resources of the region is needed to determine the appropriate bio-energy development strategy and the policies and institutions to go with it – so as to serve the interests of both sustainable development and improved economic competitiveness for the region of Southern Africa. ■

Acknowledgements and disclaimer

O. Ajayi provided valuable comments on an earlier version of this paper. Valuable contributions to some of the supporting analysis for this paper were provided by the members of the thematic research network Cane Resources Network for Southern Africa (www.carensa.net), which was supported through the European Commission DG-Research under contract ICA4-CT-2001-10103. Additional support was provided by the Swedish International Development Cooperation Agency (SIDA) and the Stockholm Environment Institute (SEI). The opinions expressed in this paper are strictly those of the authors and in no way represent the views of the European Commission, SIDA, SEI, or CEEEZ. Any omissions or errors are strictly the responsibility of the authors.

Notes

1. The term "modern bio-energy" is generally somewhat loosely defined as the conversion and use of biomass at higher efficiencies into more versatile energy carriers – electricity, liquid or gaseous fuels, and process heat [Kartha et al., 2005].
2. The member states are Angola, Botswana, the Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe.
3. Bio-diesel does not have the large economies of scale that are found in the case of bio-ethanol.
4. Although not assessed here, there are also possibilities for expanding the production of ethanol of higher purity, which can be sold on the higher value-added but lower volume industrial market.
5. There are hundreds of potential co-products from sugar cane of which about 50 have commercial markets in some parts of the world and have been analysed in some detail [Rao, 1998]. Furthermore, there are many varied applications for some of these co-products, resulting in additional secondary and tertiary co-products.
6. For many years, molasses was shipped from another sugar factory in the southern part of Malawi to the distillery so as to increase production, but the transport of molasses by road was imposing additional costs and insecurity in supply of feedstock. Another distillery was recently built in order to avoid long-distance shipment of molasses feedstock.

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