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A sweet deal? Sugarcane, water and agricultural transformation in Sub-Saharan Africa

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ABSTRACT

Globally, the area of sugarcane is rising rapidly in response to growing demands for bioethanol and increased sugar demand for human consumption. Despite considerable diversity in production systems and contexts, sugarcane is a particularly “high impact” crop with significant positive and negative environmental and socio-economic impacts. Our analysis is focused on Sub-Saharan Africa (SSA), which is a critical region for continued expansion, due to its high production potential, low cost of production and proximity, and access, to European markets. Drawing on a systematic review of scientific evidence, combined with information from key informants, stakeholders and a research-industry workshop, we critically assess the impacts of sugarcane development on water, soil and air quality, employment, food security and human health. Our analysis shows that sugarcane production is, in general, neither explicitly good nor bad, sustainable nor unsustainable. The impacts of expansion of sugarcane production on the environment and society depend on the global political economy of sugar, local context, quality of scheme, nature of the production system and farm management. Despite threats from climate change and forthcoming changes in the trade relationship with the European Union, agricultural development policies are driving national and international interest and investment in sugarcane in SSA, with expansion likely to play an important role in sustainable development in the region. Our findings will help guide researchers and policy makers with new insights in understanding the situated environmental and social impacts associated with alternative sugar economy models, production technologies and qualities of management.

1. Introduction

Sugarcane is an important crop globally. Whilst the health effects of sugar consumption are vigorously debated (Ruxton et al., 2010), and there is uncertainty about its future as a biofuel feedstock, supporting and expanding sugarcane production is an economically important element of the development agenda in many Sub-Saharan Africa (SSA) countries.[1] Significant future expansion of sugarcane is likely to have major impacts and repercussions on agricultural land use and water resources, livelihoods, food security and ecosystem services, whilst potentially providing major infrastructure and economic benefits. Further development of the sugar sector will take place against

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[1] The SSA designation is commonly used to indicate all of Africa except Algeria, Egypt, Libya, Morocco, Tunisia and Western Saharam—the Sudan and the islands of Madagascar and Mauritius are included in SSA. http://unstats.un.org/unsd/methods/m49/m49regin.htm.

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a backdrop of a changing climate with greater rainfall uncertainty and increased drought risk putting pressure on yields in rainfed production (Knox et al., 2010), rising demand for irrigation and reducing available water supplies (Kusangaya et al., 2014). An increased reliance on fertiliser to improve crop yields coupled with the introduction of new varieties resistant to climate variations based on genetically modified cane could also lead to major unintended consequences for local ecosystems.

Cane production and processing are important sources of employment and foreign exchange to SSA but are associated with potentially intense demands on water and other environmental resources. Cane plays a central role in a number of current policy and academic debates. Some, for example, look to the cane industry for tried and tested models for linking small-scale producers to value chains through outgrower schemes. The argument is that models such as these can help power the transformation of African agriculture. Others link cane production to the strong focus on infrastructure development that is evident in much of the continent. There is, for example, close alignment between the plans for water, transportation and power infrastructure in the development corridors of eastern and southern Africa, and the requirements of a modern, large-scale sugar industry.

However, there are also those who use examples in the African sugar industry to illustrate trends in global agriculture that in some cases can override national policy and affect local business and livelihoods. Sugar development has, in particular cases, been linked to land and water 'grabbing' (e.g. Matavel et al., 2011) as well as negative downstream effects including reduced annual and low flows and increased sedimentation (Jewitt and Kunz, 2011). More generally, sugarcane can be placed at the centre of debates on the water-food-energy nexus and the pressures on the agricultural sector to increase crop productivity and improve water use efficiency. The recent global interest around the use of sugarcane as a biofuel stock (EurObserv'ER, 2012) puts the economic, developmental and environmental trade-offs that are at the heart of this nexus into stark relief.

Sugarcane has characteristics that are associated with particular environmental and social outcomes. These include the crop's water requirements, and in SSA, the high reliance on irrigation for production. Additionally, sugar cane quality deteriorates rapidly after cutting, so the cane needs to be moved promptly from the field to the mill. As freshly cut cane has high water content, it is expensive to transport. Therefore to limit costs, cane is generally grown close to the factory site and can dominate the land use in the locality of the mill. This concentration of activity results in a need for significant infrastructural support, including housing, roads, schools, medical facilities and recreational facilities for people employed in the growing, cutting and processing of cane. There are also potential economic returns to scale; and, depending on the technology used, potentially high labour demands for both cane production and processing. Individually, none of these characteristics are unique to sugar production in SSA, but when they coalesce in particular production systems and locations, significant economic, social and environmental impacts (positive and negative) are possible.

The argument that we make in this paper is that despite the considerable diversity of sugarcane production systems observed in SSA, sugarcane should be considered as a particularly "high impact" crop in relation to both water and labour. We use the term high impact to refer to a crop associated with significant positive and/or negative environmental and/or socio-economic impacts. This argument underpins our interest in the situated environmental and social impacts associated with different sugar economy models (mega-estates, independent growers, small-scale outgrowers, mixed models), production technologies and qualities of management. Ultimately we are interested in the circumstances, or combinations of factors, that would favour models of sugarcane development in SSA that are both more environmentally sustainable and socially acceptable, and how current industry trends and existing agricultural development policies map onto these. In this context, and as part of a broader international effort to understand the environmental and hydro-social impacts of global sugarcane expansion, the objective of this paper was to provide a critical assessment of scientific evidence, expert and industry opinion on the water, land, economic and social impacts of the sugarcane industry in SSA. As such our focus is on trends in cultivated area and production, the impacts on land and water resources and the industry's links with regional economic development and rural livelihoods. By combining geospatial data on sugarcane croplands with water resources availability, we assess the rainfed and irrigated areas 'at risk' to develop new insights on the geographical variation in water resources and their political and social consequences. In the concluding section of the paper we identify the future opportunities and emerging research questions for the scientific community. The paper is based on a combination of evidence from a review of the literature, a research-industry workshop, discussion with key informants including stakeholders and industry, and expert opinion. First we review the current status of sugarcane production in SSA and then discuss the evidence from the literature for the environmental and social impacts of sugarcane expansion. We conclude by considering the way forward and the potential contribution of expanded production of sugarcane to sustainable development in SSA.

2. Sugarcane production in SSA

Globally, sugarcane is the 14th most extensive crop in terms of cultivated area, equivalent to ~1.75% or 26.5 M ha of the total global cropland area (Leff et al., 2004). In 2013 global production of sugarcane was estimated to be 1.9 Gt, with Brazil and India accounting for 39% and 18% of global production, respectively (FAOSTAT, 2015). Although SSA represents only 4% of current global production, it is considered a critical region for continued expansion due to its high production potential, low cost and proximity to European markets (Tyler, 2008). Fig. 1 shows the reported spatial distribution of sugarcane production across Africa, derived from modelling studies, highlighting regions of concentration in west, east and southern Africa.

Sugarcane is grown in most countries in SSA, but five account for more than half the total production (FAO, 2015): South Africa (23%), Sudan (including South Sudan) (9%), Kenya (7%), Swaziland (7%) and Mauritius (7%). Sugarcane production in SSA more than tripled between 1961 and 2013 (Fig. 2) (Jolly, 2012; Kalinda and Chisanga, 2014). The overall trends in sugar production are, in part, climate related, for instance the impact of drought conditions in 1993/4 contributed to a significant reduction in production.

Costs of production in SSA are relatively low, due primarily to the ideal growing conditions (undulating topography, clay soils, availability of supplementary irrigation, and ambient weather conditions—notably temperature and solar radiation) supporting high growth rates and conversion to sucrose. Sugarcane production is reported to achieve the highest yield between latitudes of 30°N and 30°S (Watson et al., 2008) which essentially encompasses all of SSA. For example, the sucrose production of southern African sugarcane typically averages >1 t/ha/month, whereas the global average is 0.5 t/ha/month (Tyler, 2008). The SSA region therefore has high production potential with sugarcane understandably attracting significant international interest as a commodity crop with high investment potential.

Cane production in SSA takes place in a variety of contexts, on different scales, and using contrasting technologies and organisational forms. Sugarcane may be rainfed or irrigated; produced on

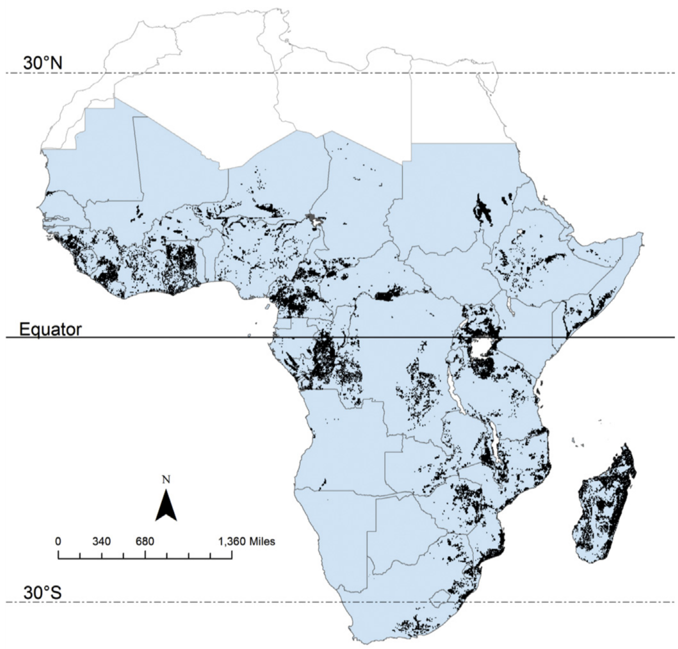

Fig. 1. Spatial distribution of sugarcane production areas in Africa based on modelled data (After: HarvestChoice, 2015a,b).

large commercial estates, or grown by out-growers whose plots range in size from very large to very small; in large flat fields or in small fields on steep slopes, and cut by hand or harvested mechanically. Cane may be transformed into raw or refined sugar, or ethanol, in factories that may be owned by international, regional or local firms, or by out-grower associations using more or less efficient factory technologies; and sold onto domestic, regional or international markets.

One increasingly important narrative paints the sugar industry as a critical part of agricultural and economic development strategy in Africa, through its contributions to infrastructure development, job creation and the balance of payments (Lankford and Dickinson, 2007; Watkins, 2004; Watson et al., 2008). This narrative is compelling because many of the region's sugar-producing countries are among the poorest in the world. A number of Southern African Development Community (SADC) countries, including Tanzania, Malawi, Zimbabwe and Mozambique (SADC, 2013) have identified sugarcane production as a key component of major initiatives to develop so-called growth corridors (Paul and Steinbrecher, 2013).

2.1. A complex institutional environment: markets, quotas and prices

Due to its relative geographical proximity and colonial history, the Europe Union (EU) market has been particularly important to Africa's sugar sector. The EU is the world's second largest consumer of sugar (Czarnikow, 2014) and was the largest importer of sugar between 2008 and 2011 (ISO, 2014). Many SSA counties benefited from schemes giving preferential access to the EU market, making sugar production especially attractive. These were initiated as part of the 1975 Lomé Convention between African, Caribbean and Pacific (ACP) countries and the EU, and were retained in the follow-on Cotonou Agreement signed in 2000. Duty-free and quota-free access for sugar is enshrined in the new generation of economic partnership agreements (EPA) between ACP countries and the EU. In addition, least developed countries (LDC) which were not ACP countries or which had not yet signed an EPA (e.g. Malawi, Mozambique, Zambia), still enjoy duty and quota-free access to the EU market under the 2001 Everything-But-Arms Initiative.

The price of sugar was particularly high for ACP countries before 2006 as the EU bought their sugar at preferential prices that were typically double or triple the world market price (Terry and Ryder, 2007). Although the EU decreased its reference price for sugar by 36% between 2006 and 2010 after undertaking major European sugar reforms, this price was still higher than the world market price (Jolly, 2012), continuing to offer beneficial conditions for ACP and LDC countries. In addition, sugar prices in the EU have been particularly high in the past few years, which has benefited exporters to Europe (European Commission, 2013). After 2017, production quotas within the EU are to be lifted and as a result, it is

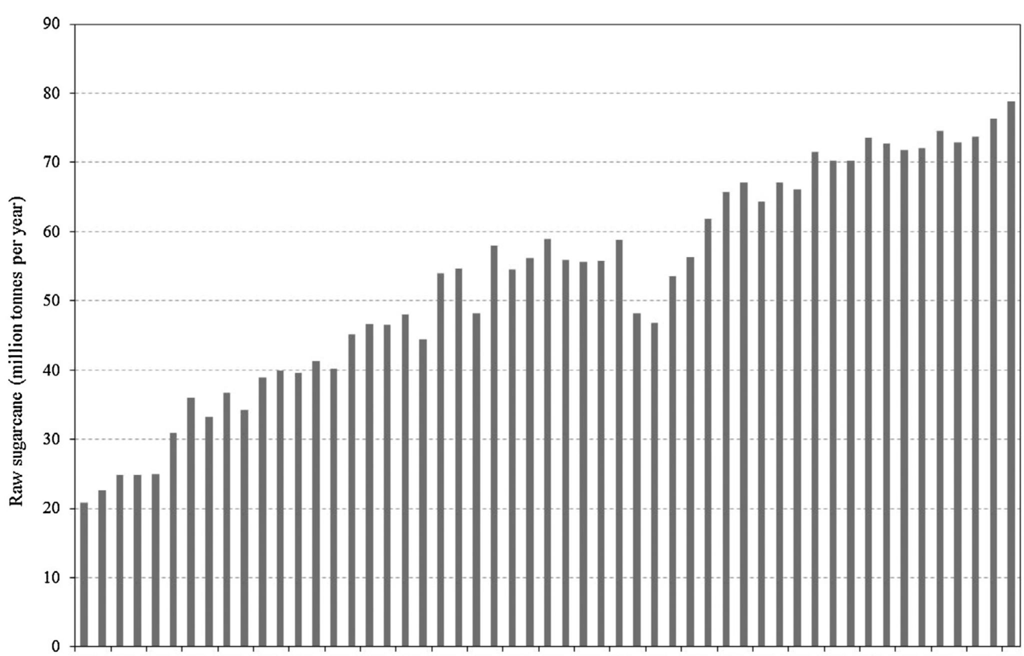

Fig. 2. Reported annual sugarcane production (Million tonnes per annum) for Sub-Saharan Africa between 1961 and 2013 (Source: FAOSTAT, 2015).

predicted that by 2023 sugar imports into the EU will be at only a half their 2010 level (Agritrade, 2014).

The Africa-EU and regional market dynamics create peculiar opportunities and niches. South Africa supplies its neighbour Mozambique with sugar for domestic consumption and to supply the drinks industry, because the majority of Mozambique's own production is exported to the EU in order to capture higher prices (Sulle et al., 2014). Similarly, corporations from countries which have not benefited from unrestricted trade access to the EU, such as South Africa, and international corporations from the UK and France, have moved to expand operations in some of the poorer countries in the region to take advantage of these trade agreements (Yamba et al., 2008). For example, Illovo Sugar Ltd. operates in six southern African countries and is reported to generate 80% of its profit from non-South African operations; AB Sugar (who own a 51% stake in Illovo) was able to supply its sugar refineries in Europe with mostly duty- and quota-free sugar from its southern African operations (Richardson, 2010).

2.2. The influence of biofuels

A major driver of demand for biofuels is renewable fuel-blending mandates, with the aim of reducing greenhouse gas emissions, and the EU's inability to meet them (Richardson, 2010). However, it is not altogether clear whether the demand for biofuels, especially ethanol (Locke and Henley, 2013), has yet had a significant impact on sugarcane production in Africa (Thaler, 2013). Most of the ethanol produced in tropical countries uses sugarcane products (cane juice or molasses) as a feedstock (FAO, 2008) and some biofuel projects based on new sugarcane plantations have emerged as a result (Shumba et al., 2011). However, Jolly (2012) argues that in the SADC countries, increased global demand for ethanol has not equated to a higher production of sugarcane. The relatively high prices associated with the preferential trade agreements discussed above, along with high local prices in some countries mean that sugar is targeted to these markets. Demand for biofuels is extant and increasing, giving sugar producers a reason to turn excess molasses from the milling process into ethanol. Some producers are gearing up to take advantage of this opportunity by investing in modern sugar mills with the capacity to produce ethanol directly from cane juice (Annual SADC Sugar Digest, 2013). Some African countries, notably Mozambique, have also attempted to emulate Brazil's success in cane ethanol production, by relying heavily on Brazilian biofuel technology expertise and development assistance. Demand for technical and financial support has coincided with Brazil's desire to increase South–South cooperation and leverage its historical and cultural ties with Africa for mutual economic benefit (Thaler, 2013). This has provided an opportunity to take advantage of Africa's low-cost environment to expand ethanol production and access preferential local and international (e.g. China) markets. Driven by growing concerns regarding the environmental sustainability of biofuels and particularly issues relating to high water usage and high greenhouse gas emissions associated with land preparation for energy cropping, an alternative strategy now being considered in South Africa is the use of lignocellulosic feed such as sugarcane bagasse for second generation biofuels (Petersen et al., 2015). This would not only threaten new biofuels entrants into the SSA market based on sugar cane, but could also impact on the current dynamics of sugar cane from a water-energy-food (WEF) nexus perspective.

As a number of African countries are entirely reliant on imports to meet their transportation fuel needs, many have announced the introduction of mandatory blending requirements (von Maltitz and Setzkorn, 2013; Lane, 2013; Pacini and Batidzirai, 2012). This may help reduce foreign exchange outlays (Franco et al., 2010) while achieving a greater level of energy autonomy. For the region's sugar producers, faced with increasingly less-advantageous EU prices, combined sugar and ethanol production may be an attractive way to add value to the sugar supply chain (Borras et al., 2011). Ethanol production does not necessarily require additional cane production, or impact on sugar output, as much ethanol is produced from molasses, which is an often underutilised by-product of sugar factories (Chamdimba, 2009; Yamba et al., 2008). Again, this vision of a modern, flexible sugar industry that can make a strategic contribution to the national energy economy is an important part of the rationale for sugar production and processing having a key place within the large-scale growth corridors.

3. Land, water, soil and atmosphere impacts

Commercial sugar cane production is associated with potentially large-scale land use change, both direct and indirect, and thus impacts on water, energy and nutrient cycles. Depending on the scale of development and choice of production system, these impacts will become evidentat local and regional scales. However, assessing the extent of these changes and impacts is challenging.

3.1. Land use change

The drivers and opportunities to produce sugarcane with high sucrose levels at relatively low cost, preferential access to the EU market, and the promise of increased demand for bioethanol have fuelled recent interest in the expansion of sugarcane in SSA. With an estimated 6 million hectares of land available for sugar production in six southern African countries, and with the estimated potential in Malawi, Mozambique and Zambia alone being greater than all of the existing sugarcane production in the SADC region (Watson et al., 2008), there is a perception of abundant land for expansion (Watson, 2011). In some cases sugarcane development occurs through the rehabilitation of existing estates, while other cases involve the conversion of existing agricultural land previously used by small-scale producers, or development of large-tracts of previously uncultivated land. The two latter routes imply direct and/or indirect land use change, and both warrant careful consideration. Expansion through conversion of existing agricultural land may involve dispossession, displacement and disrupted livelihoods, which can reduce food production and threaten food security. Expansion through development of previously uncultivated land may disrupt long established grazing patterns and gathering activities, threaten biodiversity and disrupt other land-related ecosystem services. Thus even conversion of previously uncultivated land could have important livelihoods and ecosystem side-effects. Ultimately the significance of these effects will depend on local circumstances and the type and scale (i.e. an individual estate or sugar cluster within a development corridor) of sugar development.

To date there have been few studies of land use change associated with sugarcane expansion in SSA. By comparison, the development of sugarcane in Brazil displaced mainly pasture and agricultural lands, with only 0.6% displacing forest or reforested areas (Adami et al., 2012; Zuurbier, 2008). Some authors have argued that even though sugarcane expansion has not directly replaced natural biomes, it has had an indirect impact when the agricultural activities that are displaced by expansion move towards or into natural or sensitive biomes. Unlike direct land-use change, indirect change is more challenging to evaluate (Zuurbier, 2008) however, literature from Brazil confirms a negative and statistically significant correlation between sugarcane expansion and deforestation (de Sá et al., 2013).

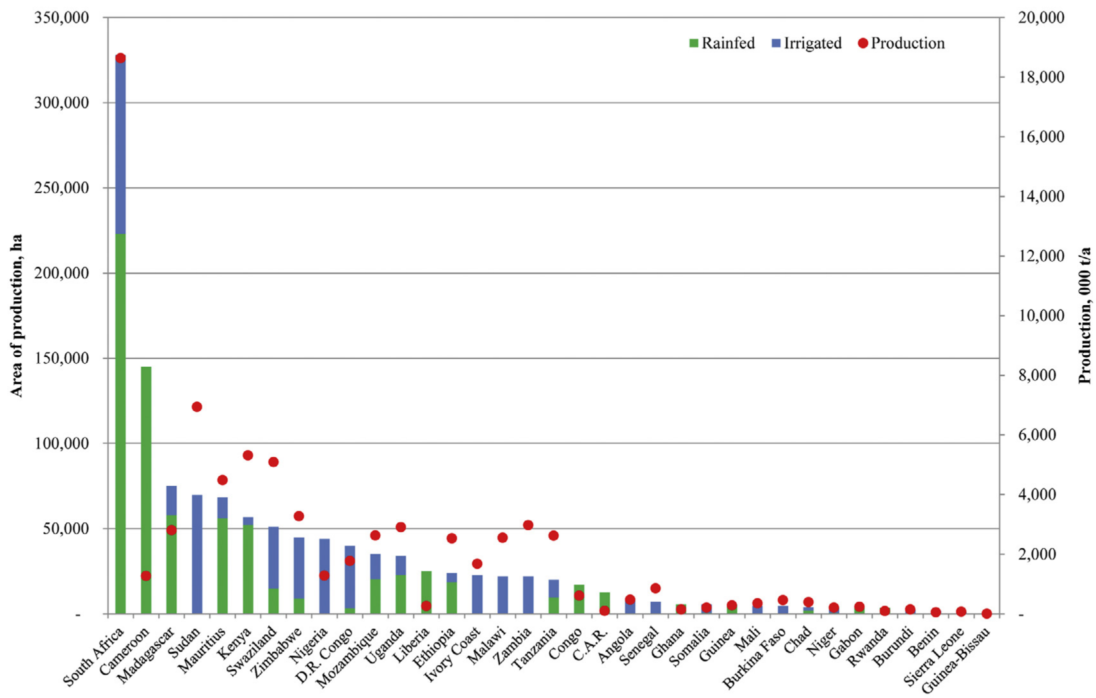

Fig. 3. Sugarcane harvested area (ha) and average production (×000 t) by country in SSA (Source: HarvestChoice, 2015a,b; FAOSTAT 2015).

3.2. Water resources

Water is a crucial resource to the sugar industry both for cane production, processing and refining (Hess et al., 2014). The impacts of sugarcane expansion on water resources will depend on local agrometeorological conditions, whether the crop is rainfed or irrigated, and the land cover it replaces (Bagley et al., 2014). Irrigation is required in geographical regions where rainfall is insufficient to meet plant water demands (Fig. 3). Apart from Cameroon and Mauritius, a significant proportion of the cropped cane area in many SSA countries relies on irrigation. A regression of the annual sugarcane production (t) in SSA against irrigated and rainfed areas (ha) shows that the irrigated sugarcane has, on average, approximately three times the productivity (98 t/ha) compared to rainfed sugarcane (32 t/ha). However, there is potential for sugar production to have significant impacts on local water availability by reducing both the quantity and quality of water for other uses.

The withdrawal and transmission of water from rivers, groundwater or constructed reservoirs can affect flow regimes and aquifers further afield. As with any irrigated cropping, the impact on downstream water availability will depend on the location of production within the catchment as well as on local soil and topography conditions, farm management practices and local climate conditions (Schmidt, 1997). In contrast to other irrigated crops which are fallow and/or unirrigated during part of the year, sugarcane is a perennial crop that can be irrigated all year, thus increasing annual water consumption compared to other irrigated cropping systems. In addition, sugar mills and refineries also require large quantities of water, with cane washing estimated to require 3–10 m^3 per tonne (Cheesman, 2004). Because of the concentration of production around factory sites, sugarcane may have great potential to modify local water balances and therefore affect available water supplies for competing uses (household/domestic/industrial supply, environmental flows) and impact the quality and dynamics at watershed level and beyond. India, the world's second largest producer of sugarcane, provides an extreme example where irrigated sugarcane has contributed to severe scarcity of both surface and groundwater at a range of spatial scales in several river basins (Shrivastava et al., 2011; Rodell et al., 2009). There is pressing need to avoid the trap of groundwater-dependent irrigated sugarcane that rapidly undermines its sustainability through groundwater overdraft, especially in northern India where deep aquifers are being rapidly depleted, though the decentralized nature of groundwater extraction in India complicates effective governance (Shah, 2010).

It is not only irrigated cane that can impact stream flows, but also rainfed cane. An increase in the area of rainfed sugarcane might lead to a change in available water resources, as sugarcane may have a different annual water use to the land uses that it replaces (Warburton et al., 2012). In Brazil, modest, or even positive impacts of sugarcane on surface water quantity have been identified as water use under rainfed sugarcane is comparable to the native forest during the growing season, but lower for several months following harvest (Georgescu et al., 2013). Similarly, Loarie et al. (2011) reported lower mean annual crop water use under sugarcane compared to the original cerrado forest, but sugarcane conversion from agriculture (crop and pasture) resulted in increased crop water use (Table 1).

SSA is characterised by a range of hydro-climatic regions with high rainfall variability (Conway et al., 2009). In general terms, SSA cannot be considered water poor (Lautze and Giordano, 2007) as it stores 9% of the world's freshwater resources. With only 11% of the global population in SSA, it also has a lower per capita rate of water withdrawal and lower level of irrigated area than any other region globally. However, some countries, including Sudan, Swaziland and Tanzania, have significant areas of both rainfed and irrigated production within areas of 'high' or 'extremely high' water risk (Gassert et al., 2014) (Table 2). This means that not only is sugarcane production exposed to risks from reduced water availability (in the case of irrigated sugarcane), but also that cane production may be exacerbating water risks to other users in the catchment.

In South Africa, 60% of the country's water supplies are already fully committed, and the Government has highlighted the severe limitations on the availability of additional water for allocation to

Table 1
Total irrigated and rainfed sugarcane harvested areas (ha) in SSA within different water risk categories (After: HarvestChoice, 2015a,b; Gassert et al., 2014).

Sugarcane production	Water resource risk[a]				
	Low	Low to medium	Medium to high	High	Extremely high
Rainfed	76.1	246,302	419,411	27,584	52
Irrigated	–	95,716	360,958	48,107	3129

[a] Physical water risk is defined as the exposure to changes in water quantity that may impact a company's direct operations, supply chains and/or logistics.

Table 2
Estimated area (ha) of rainfed and irrigated sugarcane in SSA within areas defined as 'high' and 'extremely high' water risk (Sources: HarvestChoice, 2015a; Gassert et al., 2014).

Country	High water risk		Extremely high water risk	
	Rainfed area (ha)	Irrigated area (ha)	Rainfed area (ha)	Irrigated area (ha)
South Africa	27,788	6441	–	–
Swaziland	–	24,790	–	–
Sudan	–	17,443	–	2732
Tanzania	38	9520	–	–
Nigeria	–	4415	–	–
Madagascar	191	1972	–	671
Somalia	61	2422	63	253
Mozambique	987	502	4	–
Ethiopia	1261	153	–	2
Chad	–	21	–	244
Niger	–	–	–	163
Kenya	2	60	–	–

new uses (DME, 2007; Mapako et al., 2012). Competition for water resources in certain catchments in South Africa is forcing the sugar industry to justify its use of irrigation on the basis of economic return to water used (Schmidt, 1997). Although 80% of sugarcane in South Africa is not irrigated, the low ratio of runoff from rainfall, spatial heterogeneity in rainfall patterns and the high intra- and inter-annual variability make water resources highly sensitive to changes in land cover (Jewitt and Kunz, 2011). As a consequence, growers may be required to apply for a water licence even under rainfed conditions under the National Water Act (Government of South Africa, 1998) which allows for the regulation land-based activities which reduce stream flow (Stream Flow Reduction Activity) (Jewitt et al., 2009). Some studies (e.g. Mozambique's Limpopo River Basin) have recommended limits to planned sugarcane developments (Van der Zaag et al., 2010) however, other countries, including Tanzania and Zambia, appear determined to commit adequate water resources to supply agricultural development projects in recognition of their economic contribution (Kgathi et al., 2012).

Future changes in irrigation technology to support outgrower sugarcane expansion could also create new water resource management challenges. For example, in South Asia, the availability of small electric pumps has supported rapid expansion of irrigation by smallholders, with concomitant challenges in managing the activities of millions of individual well operators (Shah, 2010). Given current and projected economic growth rates in Africa, there will likely be major shifts in technology used for sugarcane production (and other crops) and watershed management that may impact on water resources more than simply expansion of the cane cultivated area.

3.3. Water quality

Published studies on water quality impacts of cane in Africa are very limited and focus on nutrients and salinity, highlighting the limited extent of agrochemical monitoring at the catchment scale. As with other large-scale commercial crops, sugarcane production involves the application of fertilizers, herbicides and pesticides. Consequently, an increase in nutrient loads, salinity and dissolved and suspended solids are the most common threats to water quality in bodies receiving outflows from sugarcane farms. The impact of growing sugarcane on water quality ranges from the field to catchment levels through rivers and lakes, shallow and deep groundwater, and even reaching estuarine and coastal areas. Several studies report water contamination from cane farming practices, mainly associated with fertiliser and pesticide application (i.e. rates and the timing of application) or as a consequence of the method of harvesting (manual harvesting with pre-burning increases the concentration of dissolved and suspended solids) (Table 3).

Herbicides are the most widely used agro-chemical in sugarcane production (Armas et al., 2005); water contamination risks are extensively covered in the scientific literature based on studies in Australia, the USA and Brazil. Surface waters in areas of sugarcane production have also been shown to contain herbicides and pesticides sometimes exceeding ecological (e.g. Davis et al., 2013) or drinking water (e.g. Mitchell et al., 2005) guidelines. The impacts of sugarcane production on water quality are also linked to the activities of sugar mills and refineries (Pawar et al., 1998; Shivappa et al., 2007; Tchounwou, 1999). Studies on the effects of waste water from ethanol production have highlighted increases in organic matter, higher concentrations of total suspended solids, and an increase in temperature of receiving waters (Smeets et al., 2008).

It is evident that without sufficient environmental and regulatory controls, future expansion of sugarcane in SSA could pose a threat to water quality. Given the scarce nature of water resources in parts of the region, pollutant loads are likely to be higher in rivers and lakes putting drinking water supplies at risk. However, new environmental regulations, including the implementation of ISO standards and participation in BONSUCRO (http://www.bonsucro.com) accreditation, are helping to mitigate these impacts particularly for new cane developments. Understanding the impacts of high seasonal variability will also be pertinent, and some adaptation in farming techniques will be needed to minimise future water quality risks.

Table 3
Summary of reported impacts associated with sugarcane production on water, soil and air quality by study location.

Receptor	Impact	Location	Source
Surface water bodies	Increased nutrients concentration in runoff	Mauritius	Ng Kee Kwong et al. (2002)
		Florida, USA	Rice et al. (2002)
		Uganda	Munabi et al. (2009)
		South Africa	Van der Laan et al. (2012)
		Queensland, Australia	Faithful and Finlayson (2005), Mitchell et al. (2005)
		Louisiana, USA	Yu et al. (2008)
	Increased pesticides and herbicides	Queensland, Australia	Müller et al. (2000), Mitchell et al. (2005), Camenzuli et al. (2012), Davis et al. (2013)
	Increased suspended and dissolved solids	Swaziland	Mhlanga et al. (2006)
		Queensland, Australia	Roth et al. (2003), Faithful and Finlayson (2005)
		Louisiana, USA	Yu et al. (2008)
	Increased salinity	Swaziland	Mhlanga et al. (2006)
Groundwater bodies	Increased nutrient concentrations	Queensland, Australia	Rasiah et al. (2005), Rasiah et al. (2013)
Soil	Acidification	South Africa	Schroeder et al. (1994)
		Papua New Guinea	Hartemink (1998a,b)
	Elevated phosphorus status	Mauritius	Mardamootoo et al. (2010, 2012, 2013)
	Nutrient depletion	Papua New Guinea	Hartemink (1998b)
		Fiji	Masilaca et al. (1986)
	Reduced microbial activity/biomass	Brazil	Sant'Anna et al. (2009), da Silva et al. (2012), Souza et al. (2012)
		South Africa	Dominy et al. (2002), Haynes et al. (2003)
		Queensland, Australia	Holt and Mayer (1998), Stirling et al. (2010), Brackin et al. (2013)
	Reduced soil carbon	Brazil	Cerri and Andreux (1990), Silva et al. (2007), Sant'Anna et al. (2009)
		South Africa	Dominy et al. (2002), Haynes et al. (2003)
		Fiji	Masilaca et al. (1986)
	Reduced soil loss	Brazil	Macedo (2007)
Air	Greenhouse gas emissions	Brazil	Bordonal et al. (2015)
		Australia	Denmead et al. (2010)
	Pollution	Brazil	Tsao et al. (2012)
	Local climate changes	Brazil	Loarie et al. (2011), Georgescu et al. (2013)

3.4. Soil and land management

Sugarcane is grown under a wide variety of management regimes in SSA ranging from large commercial plantations to smallholder farms. Long-term production of sugarcane has been shown to have both a negative impact on soil properties and crop productivity (Garside et al., 2001; Meyer and Van Antwerpen, 2001) but also a positive effect with green cane harvest improving soil biology and nutrient cycling (Borges et al., 2014; Trivelin et al., 2013). The management systems on large plantations generally use intensive farming methods which are often semi-mechanised, putting pressure on soil resources and modifying soil physical, chemical and biological properties. Trafficking heavy machinery in-field can lead to compaction and reduced soil porosity, decreased soil aeration and increased soil resistance (Swinford and Boevey, 1984). These changes in turn can impact negatively on root growth and ultimately affect yield. There are moves, however, to systems of controlled trafficking, especially for cane harvesting and haulage, which can reduce the level of damage infield and contribute to significantly higher yields and increased profitability (Lecler and Tweddle, 2010). Smallholder systems tend to be less mechanised, but can nevertheless also be detrimental to soil conditions, for instance due to soil erosion caused by a lack of appropriate conservation measures.

Continuous cropping with sugarcane has been shown to lead to increased soil acidification, nutrient depletion and reduced soil microbial activity and biomass (Table 3) compared to other agricultural land uses or natural vegetation, although studies in Mauritius (Mardamootoo et al., 2010) identified elevated soil phosphorus resulting from years of over application of fertiliser. Soil carbon content and soil microbial activity tends to decline with long-term sugarcane cultivation compared to natural vegetation and other agricultural systems.

3.5. Greenhouse gas emissions

Greenhouse gas emissions are associated with all crop production activities, and for sugarcane arise through field management, fertilization and especially burning prior to harvest (Table 3). However, the degree to which conversion to sugarcane changes emissions depends on the net emissions of the previous land use. Where natural forests have been converted to sugarcane net emissions may increase, while the replacement of other agricultural land uses with sugarcane can result in a net decrease in emissions (Bordonal et al., 2015).

Process-based physical models that represent interactions between the landscape and the overlying atmosphere indicate that direct, biogeophysical (e.g., due to albedo) changes associated with conversion of annual to perennial crops can be at least as important as biogeochemical effects (Georgescu et al., 2011) and conversion to sugarcane can impact on local climate. The replacement of shallow with deeper rooting systems associated with perennial bioenergy crop deployment can lead to depletion of water within the soil column, modification of the water table, and consequential effects for regional hydroclimate. Significant and rapid warming may occur after sugarcane harvest, which may gradually be offset as the crop reaches maturity (Georgescu et al., 2013).

4. Social impacts

The spatial concentration and close proximity of cane production areas to processing plants means that in terms of employment and local economic effects, the footprint of sugar production can be relatively small but very deep. Beyond an estate-factory complex, the spatial link between a group of cane growers and a single factory creates a strong dependency: sugarcane growers, whether large or small, seldom have any choice as to the factory to which they send their cane. This means that the relationships between farms, factory, workforce and the local economy can be very tightly coupled. The main social impacts are thus evident through employment and livelihoods, food security and land availability, and health.

4.1. Employment and livelihoods

The most significant direct social impact associated with sugarcane production arises through the employment it generates. Across SSA thousands of individuals are employed directly on sugar estates and in mills, while others work as, and for, outgrowers (independent farmers contracted to grow sugarcane on their own land to supply to mills and/or estates) and in the provision of the many goods and services that support sugar production. Earnings from sugarcane indirectly support many other local businesses and small-scale economic activities. Unfortunately, there are no current comprehensive and robust estimates of the levels and types of employment associated with sugarcane production and processing in SSA. The South Africa Sugar Association (SASA) estimates that 79,000 direct jobs and 350,000 indirect jobs are associated with production and processing in South Africa (SASA, 2014). If this estimate is both correct and representative, then projecting on the basis of jobs per ton of sugar produced would suggest that there may be as many as 1.8 million jobs associated with the industry in SSA.

Whilst working conditions of employees vary tremendously, manual cane cutting is known to be particularly arduous, with some cutters in the past being treated brutally. Whilst Robins et al. (1998) reported that 14% of workers in sugarcane fields in South Africa in 1998 were physically abused by farm management staff, modern labour regulations have dramatically improved employer-employee relations. On the other hand, within the southern Africa sugar industry there is increasing casualization of labour associated with industry restructuring, changing aid frameworks and market incentives, and mechanisation (Oxfam International, 2004; Richardson, 2010; Richardson-Ngwenya and Richardson, 2014). Casualization and seasonal employment, with labourers being repeatedly hired on short-term contracts, seasonal absolve employers of responsibility for providing benefits such as pension contributions, health and social services and employment security, and also greatly increases the challenges associated with establishing and maintaining representation through labour unions (Richardson-Ngwenya and Richardson, 2014). In Brazil, human rights concerns and pressure to reduce burning prior to harvest have hastened the shift to mechanical harvesting, thus reducing the industry's demand for less educated labour.

The range of skills needed to support sugarcane production is reflected in wage and salary levels. However, there is no evidence that allows a systematic analysis of earnings in comparison to other agro-industries. Oxfam International (2004) reported that salaries on plantations in Mozambique were very low, and, according to trade unions and certain civil society organisations, did not constitute a living wage. Nevertheless, the same report also noted that jobs in the sugar industry were highly valued and considered better than available alternatives. This is reflected in the fact that since the rehabilitation of two sugar mills in Sofala Province, employment rates had doubled and poverty rates had changed from being the highest in the country, to the lowest. Herrmann and Grote (2015) found that plantation workers in Malawi were better off than non-participants; however, while they were able avoid extreme poverty; they did not earn enough to rise above the poverty line. As noted earlier many mills provide services like clinics and schools, which are thought to play an important role in attracting and disciplining labour.

Although not formal employees, outgrowers and independent cane producers are integral to the sugar industry in SSA and represent another channel through which the industry impacts on local economies. Whilst many outgrower schemes focus on small-scale producers, it is important to remember that in some countries like South Africa, there are some very large and technically sophisticated independent cane growers.

Many studies have identified positive effects of outgrower schemes on incomes and poverty rates of smallholders, but some have warned of negative environmental impacts associated with poor agricultural practices (Clancy, 2008). Herrmann and Grote (2015) reported that in Malawi the incomes of outgrowers' were significantly higher than those of non-outgrowers, the outgrowers had significantly lower poverty indices. High income levels were also reported for the Kaleya outgrower scheme in Zambia (Shumba et al., 2011). In contrast, Richardson (2010) noted high levels of indebtedness some outgrowers face due to high capital investment costs, particularly for irrigation (Tyler, 2008). From their work in Malawi, Richardson-Ngwenya and Richardson, (2014) suggest that an important "hidden benefit" of small-scale sugar production is access to irrigation and electricity infrastructure, with can also be used for food crop production to increase food security. It would be wrong to assume that outgrowers and other small-scale cane producers will necessarily be a prominent feature of cane production throughout Africa. Dubb (2015) provides a detailed and spatially situated political economy analysis of the on-going decline of small-scale sugar cane production in the Umfolozi region of South Africa.

The mixed evidence on economic and social impacts for outgrowers reflects the complex and changing political economy within the sugar industry operates, the fundamentally asymmetrical power relations between estates/mills and outgrowers, and the quality of scheme management (Church, 2008).

4.2. Food security and land

Given the mixed record of small-scale outgrower schemes it should not be surprising that some researchers have raised concerns about negative effects on the food security of outgrower households. This echoes earlier debates regarding potential negative effects on food security when smallholders devote a significant proportion of their land to cash or commercial crops. Terry and Ryder (2007), for example, suggested that outgrowers in Swaziland, and particularly the poorer ones, were unable to meet their food requirements after converting all their land to rainfed sugarcane. With the Mumias sugar scheme in Kenya, concern was expressed that a shift to cane by small-scale producers could result in increased food insecurity (Tyler, 2008). Specifically, women lose access to lend for food crops and would also have less control over household income. Nevertheless, Kennedy (1989) could find no evidence that sugarcane production was associated with an increase in malnutrition. Moving up from individual outgrowers level and their households, some analysts and advocates argue that there is a trade-off between national food security on the one hand and expansion of the sugar industry on the other. The growing interest in biofuels and the sugar industry's requirements for high quality land and water resources have made sugar central to recent debates around land and water deals in southern Africa (Thaler, 2013; Borras et al., 2011; Richardson, 2010; Shumba et al., 2009).

Land access and tenure are perhaps two of the most important issues affecting smallholder livelihoods. Given the increasing pressure on agricultural and grazing land throughout SSA (Jayne et al., 2014), expansion of sugarcane production will likely have significant implications for some local residents. In many African countries, land is under customary tenure, and negotiations to secure land for large-scale projects, like sugar estates, can be fraught. Cotula et al. (2008) concluded that negotiations often took place on an unequal footing: corruption, local inhabitants not knowing the commercial value of their land, a lack of legal knowledge and local level politics and power relations all come into play. Even with a well-negotiated deal, companies can fail to comply with agreed terms.

Both Thaler (2013) and Borras et al. (2011) focus on a high profile 'land grab' by a British company that proposed to produce ethanol and sugarcane on a new 30,000-ha plantation in Mozambique. The company had apparently negotiated with the local community, but did not respect the agreement, and began to encroach on people's land. Thousands of people were to be displaced. The project did not proceed for financial reasons, which turns out to be a very common outcome for planned large-scale land developments. Nevertheless, this development was in stark contrast to the Mozambican President Armando Guebuza's words "biofuel development will not dislodge Mozambican farmers from their lands" (Borras et al., 2011, p. 217). Other instances of large displacements of people due to 'land grabs' for sugar production have also been documented. For example, Richardson (2010) reported on the case of 1100 households displaced in Mozambique as a result of land and water grabbing by sugarcane companies.

The land and water requirements for new sugarcane development put an expanding industry on a collision course with Africa's small-holder dominated and increasingly land-hungry agrarian economies. The sugar industry might both contribute to and benefit from the structural transformation of these agrarian economies that many observers argue is so badly needed. It will, however, essentially respond to international capital and commodity markets, and evolving trading regimes, with the livelihoods of rural Africans being a secondary concern.

Finally, the impacts on food security arising from links between sugarcane and biofuels are an issue that often engenders negative public reaction and an area where science could inform viewpoints and decision-making. Whilst aimed principally at biofuel assessment, the Bioenergy and Food Security Analytical Framework (BEFS) developed by the FAO (2010) could also provide useful new insights regarding sugarcane as a commodity crop. For example, Felix et al. (2010) used the BEFS framework to evaluate biofuel production options in Tanzania, comparing benefits and trade-offs between different growers (smallholder farmers and commercial farmers). Arndt et al. (2010) used the BEFS framework to evaluate long-term biofuel development implications in Mozambique and Tanzania in terms of supporting growth, reducing poverty and labour transfers between intensive cash cropping and biofuel feedstocks.

4.3. Health

The vast majority of sugarcane in Africa is burned before harvest to remove extraneous cane material (Watson et al., 2008). The direct impacts of this on the environment are evident through the amount of atmospheric pollutants emitted. Research has shown that pre-harvest burning is the cause of major health problems related to lung function and the respiratory system (Arbex et al., 2014). The risk of mutagenicity related to sugarcane burning and development of cacogenic symptoms has also been raised (Prado et al., 2012; Sisenando et al., 2012). In Brazil, Ribeiro (2008) found that burning of sugarcane fields was particularly harmful to plantation workers, exposing them to greater risks of lung cancer.

There has been some attention given to the links between sugarcane production and malaria, Ghagas' disease and schistosomiasis (Phoolchund, 1991). Dusfour et al. (2010) linked the use of pesticides in sugarcane fields the increasing resistance of malaria vectors in neighbouring wetlands. In Zambia, labour migration associated with sugarcane has been associated with a 16–22% increase in HIV infection (Richardson, 2010). Other health issues include the physical and ergonomic stresses associated with cane cutting over extended periods, and risk of disease from the cramped and poor quality of housing provided to plantation workers (Richardson, 2010). Conversely, there are many sugar estates in SSA that provide healthcare facilities for both employees and local residents.

5. Concluding comments and a way forward

Fig. 4 outlines the key environmental and social challenges for sugarcane production and their inter-dependencies. Sugarcane has been an integral part of African agriculture for centuries under a variety of socio-technical and environmental conditions and through a diversity of production scales and systems. A major implication of this is that any meaningful discussion of the economic and social impacts and environmental sustainability of cane production must therefore be context specific. The scientific literature provides numerous examples where the water, social and environmental impacts of cane production is directly dependent on the quality of scheme, nature of the production system and farm management. Good agricultural management practices can reduce losses of herbicide (Masters et al., 2013), nutrients (Thorburn et al., 2011) and atmospheric pollutants (Weier, 1996, 1999; Macedo et al., 2008; Allen et al., 2010; Signor et al., 2013); carbon sequestration can be increased (La Scala et al., 2006); and the impacts of burning can be significantly reduced when the crop is harvested "green" (Galdos et al., 2009; Eustice et al., 2011; Anaya and Huber-Sannwald, 2015). Cane production, in general, is neither explicitly good nor bad, sustainable nor unsustainable. This suggests a critical role for multi-disciplinary, multi-scale analysis and planning as a foundation for any further expansion of the sector. This kind of integrated analysis will be particularly important in relation to both water and livelihoods within economic development corridors.

In SSA sugar can be produced relatively cheaply, which might be expected to lead to an expansion of production. However, if the predicted changes to the EU sugar market came to pass, only the most competitive sugar producers in SSA will be able to continue selling to Europe, while others will need to orient themselves more towards regional and external sugar markets and/or the emerging biofuel market. Kalinda and Chisanga (2014) suggest that Zambia could export its sugar within the SADC rather than to Europe, since the high freight costs it incurs as a landlocked country (up to 45% of the export price) mean it could sell its sugar more profitably over shorter distances. Nigeria is currently embarking on a programme aimed at producing 1.8 Mt/year and becoming self-sufficient by

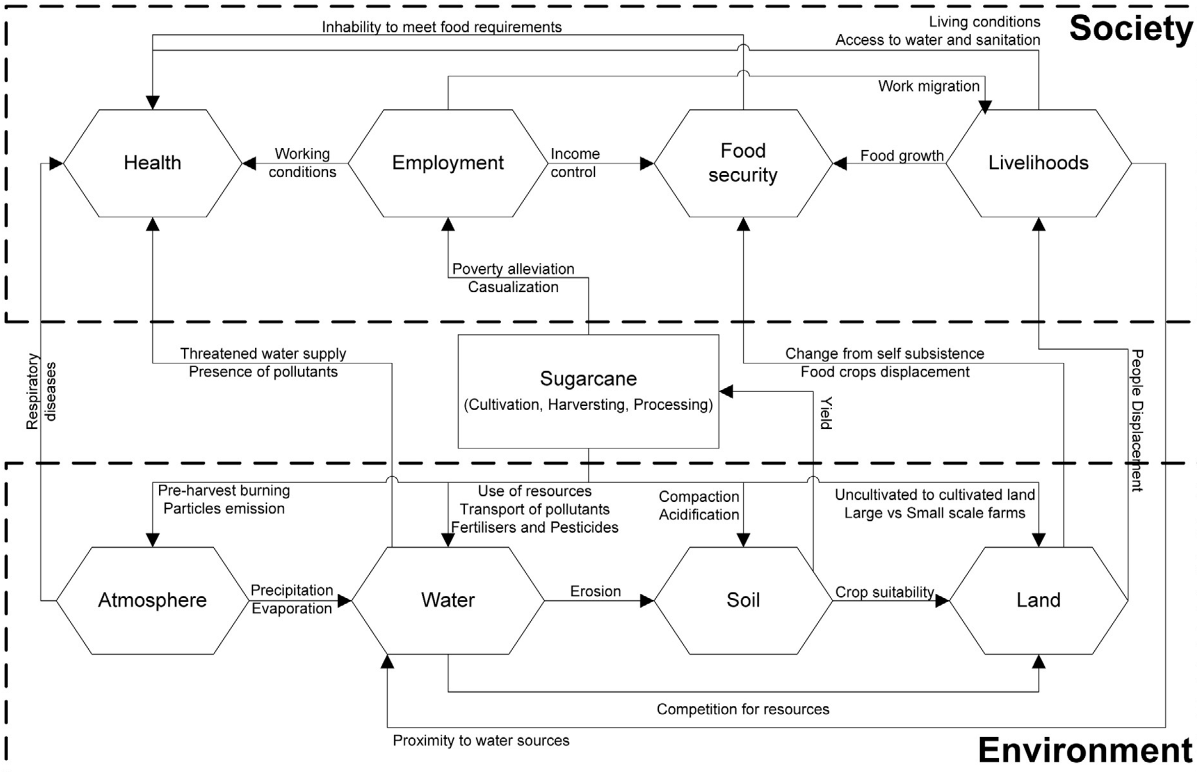

Fig. 4. Schematic representation of the environmental and socio-technical challenges facing sugarcane expansion in SSA, and their inter-dependencies.

2022. However, the Nigerian Sugar Master Plan contains a significant component of 'backwards integration' which will require refineries having to invest in sugar production in order to retain licences (Lichts, 2016). In Angola, with two mega sugar projects are set to boost southern Africa's sugar production by 15% by 2020 (SADC, 2013; Jolly, 2012). Large markets such as India, which has become a net importer of sugar (Hall, 2012), will undoubtedly also become more important.

A consequence of the highly variable climate and current lack of irrigation infrastructure means that SSA is particularly vulnerable to climate change (Callaway 2004; Knox et al., 2013) with the southern region being perhaps most vulnerable (IPCC, 2014). Among the projected effects of a changing climate, changes in the water cycle and water resources availability are often highlighted as major problems facing sustainable development in SSA (Kusangaya et al., 2014). Furthermore, most planned, large-scale agricultural developments are reliant to some extent on irrigation to ensure crop water demands are met through the growing season, thus aiming to achieve the potential yield offered by other biophysical conditions. Thus, the availability of water for irrigation is a critical constraint on sugarcane expansion and where development is intended, its potential impact on that resource must be considered carefully. It seems inevitable that future developments will increasingly depend on irrigation abstraction given the potential for yield uplift and to cope with future rainfall uncertainty (Knox et al., 2010). However, it is also important to recognise the uncertainty in assessing climate impacts on productivity; some studies investigating rainfed production suggest the impacts on future yield could be much less dramatic, both in South Africa, Australia and Brazil (Singels et al., 2013; Marin et al., 2013).

It is evident that sugar cane in SSA can be highly productive; however expansion is dependent upon the cost environment and market opportunities being favourable. From a policy perspective, because of its requirements for and association with infrastructure development, the sugar industry is seen to have a pivotal role in a number of the growth corridors. Infrastructure development, such as the construction of reservoirs, roads, pipelines and electricity has been shown to have potential positive social and economic impacts (Knox et al., 2013) well beyond sugarcane production. Opportunities for employment generation through a modern sugar industry are but one attraction. However, the industry faces a number of significant business risks including the need for high levels of capital investment to support land development, mainly for irrigation and milling infrastructure. In addition, requirements for capital investment in transportation and power networks, and establishment of local social services (housing, schools, hospitals), are considerable. Risk arises from the fact that cane is a perennial crop grown as a monoculture, and with long-term contracts tying growers to mills there is little room for adaptation to changing conditions. For example, the SSA sugarcane sector is also increasingly exposed to competition from imports of sugar and risks associated with changes in international markets. Given competing demands for agricultural land from other crops including high value fruit and vegetables for export markets, the balance of risk-reward for the sugarcane sector in SSA is becoming more uncertain.

Sugarcane production at any significant scale will also affect the availability of land for other uses, competing with food crops and natural ecosystems. Environments with suitable growing conditions for sugarcane, such as favourable soils, agroclimate and topography, as well as access to sufficient reliable supplies of good quality water for irrigation, are becoming increasingly scarce. Like other row crops, the adoption of modern water-saving irrigation technologies is often cited as being key to increasing water use efficiency while maintaining current levels of production. However, new technology requires greater capital investment, so irrigators are often reluctant to adopt new systems unless they can be convinced of the likely benefits. Where water costs are low, sugarcane growers have little incentive to switch technology to improve efficiency unless other externalities influence their ability to maximise net crop return. However, rising energy, labour and water costs, coupled with a need to increase water productivity due to increasing competition for limited resources are now driving forces influencing technology choice in cane production. If irrigated sugarcane is to be sustainable, the overriding issues will be to improve drainage management for effluent control (to reduce excess water losses, the leaching of salts, agrochemicals and nutrients) and the need to maximise water productivity (Carr and Knox, 2011).

Infrastructure, markets and water availability are current concerns for agricultural and rural development — they are important but in no way unique to the sugar industry. However, what is unique is the high environmental, economic and social impacts associated with sugarcane, the small but deep footprint that arises essentially from its high spatial concentration. The experience to date in SSA suggests that these impacts can be either positive or negative, depending on the environment, the production model, and perhaps most importantly, the quality of management. It is not so much a question of whether large estates are better than outgrower schemes or whether new hybrid business models that combine small-scale agriculture with large-scale plantations should be pursued (Sulle et al., 2014; Dubb, 2015). Rather, the research challenge is to understand better how these different models might be used in different contexts to deliver more sustainable and more equitable economic growth. The wide array of forms that exist thus present a number of important opportunities for research, including a need to understand which patterns of production are most common, the reasons underlying their geospatial variation and the factors that most influence their determination.

More broadly, it is critical to acknowledge the danger of policy narratives that portray SSA as possessing an abundance of underutilised agricultural land that with corporate investment could become the next global food and commodities basket. The current interest in development corridors in southern and eastern Africa is supported by these narratives, and it is possible – and perhaps too easy – to tie the sugar industry to them and the global and corporate agricultural futures that they both envisage and promote. An alternative narrative might be rooted locally rather than globally, and portray the sugar industry as key driver of local and sustainable environmental management and economic growth. The differences between these two visions essentially come down to the politics of capital, land, water and employment. How these politics play out in particular contexts will determine who ultimately experiences the expansion of the sugar industry in SSA as a sweet deal.

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