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UNU-IAS Policy Report

Biofuels in Africa
Impacts on Ecosystem Services, Biodiversity and Human Well-being

Biodiversity Institute Oxford

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Biofuels in Africa
Impacts on Ecosystem Services, Biodiversity and Human Well-being

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Contents

Message from the Director

Two decades have passed since nations of the world assembled in Rio de Janeiro and agreed to adopt a sustainable development (SD) agenda, promising to chart a development path that is equitable, environmentally just and economically rewarding. We now stand at a crossroads looking for the right path towards the world we want. The prognosis is not encouraging. According to many studies conducted by research or policy bodies, we seem to have made some progress, but still fall far short of what is required to sustain current levels of well-being without compromising our environment. Negative environmental trends continue to be exacerbated by human interventions—primarily led by a model of unsustainable and conspicuous consumption

The unsustainable use of ecosystem services for supporting this emerging consumer culture while ignoring the ecological consequences to economies and other aspects of well-being has become quite entrenched. Biofuel expansion in some parts of the world is such an example.

On the positive side, there is an expanding awareness and a growing acknowledgement of the negative environmental and socio-economic impacts of biofuels in policies and implementation strategies. Increasing resolve to align biofuel production with environmental and equity considerations, and efforts aimed at reforming global institutional structures are welcome signs of change. Indeed, the eleventh meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD-COP11) is seen as an opportunity to streamline various decisions that can promote biofuel sustainability.

Research and capacity building activities at the United Nations University Institute of Advanced Studies (UNU-IAS), the Biodiversity Institute at Oxford University and the Council for Scientific and Industrial Research have examined various aspects related to the rubric of governance challenges in achieving sustainable biofuel production and use.

This report analyses the impact of biofuel production and use on ecosystem services, biodiversity and human well-being in Africa. Our broader research indicates that despite the exalted nature of biofuel production as a means of promoting energy security and rural development and reducing climate change, such goals become relevant only when defined and shaped into pragmatic objectives and actions. This would require cooperative action by all stakeholder groups, implying that future policy processes need to ensure their relevance at various levels to guarantee successful implementation.

This is no easy task, but by no means an impossible one. Current accepted standards of biofuel practice and business norms must be re-oriented to include a more consultative policy setting with all major stakeholders. It would require designing regulations that on the one hand acknowledge the existence of significant trade-offs associated with biofuels, but should also put in place strong incentives that can promote the production and use of sustainable biofuels.

There are a number of expectations from the outcomes of CBD-COP11, particularly on how the existing biofuel decisions will be transformed into action and results. UNU-IAS stands ready to work with its existing and future collaborators to transform our aspirations into reality as we move forward in translating the sustainability agenda into action.

Govindan Parayil,
Director, UNU-IAS and Vice-Rector, UNU
October 2012

Executive Summary

Biofuels are a type of fuels derived from solid biomass through different chemical and biological processes. Currently, liquid biofuels (e.g. bioethanol and biodiesel) produced from edible plants or animal fats are by far the most popular biofuel types for transport purposes in the US, Brazil, EU, China and India.

Global biofuel production has increased more than fivefold in the last decade and is expected to double by 2020, mainly through expansion in developing regions such as Brazil, China, India and Sub-Saharan Africa.

Since the mid-2000s, there has been a growing interest in biofuel production and use across Africa. This has been due to policy priorities related to energy security and economic development. For example, high petroleum prices, fuel insecurity (particularly in the interior of the continent), foreign exchange savings and the potential for economic and rural development have all influenced, in varied degrees, countries across Africa to consider biofuel production. In contrast to some developed countries, environmental concerns such as the reduction of greenhouse gases (GHGs) and the improvement of ambient air quality do not seem to have been a direct driver of biofuel expansion in Sub-Saharan Africa. However, despite the recent interest from investors, several African counties were lacking appropriate policies for promoting and regulating biofuel expansion.

Jatropha (for biodiesel), sugarcane (for ethanol) and molasses (for ethanol) have been the biofuel feedstocks that have attracted the most interest across Africa, dominating proposed biofuel investments in the continent. Other feedstocks such as cassava, palm oil, sweet sorghum, tropical sugarbeets, canola oil and sunflower oil have been identified as promising but, to date, their contribution has been much lower.

Biofuel production and use in Africa have been linked to numerous environmental and socio-economic impacts such as GHG/atmospheric pollutant emissions, increased water use, water pollution, soil erosion, deforestation, biodiversity loss, income/employment generation, energy security, food security, human health and social conflicts. Whether these impacts are positive or negative depends on a multitude of factors such as the feedstock, the environmental/socio-economic context of biofuel production, and the policy instruments in place during biofuel production, use and trade.

In this report we discuss a wide array of these impacts, as they relate to jatropha biodiesel and sugarcane ethanol in Africa. A major challenge for obtaining a comprehensive picture of biofuel tradeoffs is the fact that the biofuel literature is multidisciplinary and rapidly expanding. This report employs the ecosystem services framework developed during the Millennium Ecosystem Assessment (MA), as a means of synthesizing the available evidence about biofuel impacts and identifying the main trade-offs associated with biofuels in Africa.

Our in depth review of the academic literature found that biofuel landscapes in Africa can provide, displace, divert and degrade a large number of provisioning, regulating and potentially cultural ecosystem services. These ecosystem services can link into human well-being in multiple ways. In most cases there are significant human well-being trade-offs that depend on a number of factors. Some of these trade-offs are inevitable, but in many cases at least part of the negative impact can be mitigated through careful planning.

Despite a wealth of literature there are still significant research gaps at the interface of biofuels, ecosystem services and human well-being in Africa. Our incomplete and piecemeal understanding of the main environmental and socio-economic impacts of biofuel production in Africa combined with the low yields currently obtained (mainly from jatropha projects), are at this point the most important barriers for the development of policies that can ensure the viability and sustainability of future biofuel expansion in the continent. Based on our review findings we offer a number of policy recommendations.

Recommendation 1: Adopt biofuel policies that reflect national realities and are compatible with wider policy objectives

Recommendation 2: Promote rural development through support to small feedstock producers

Recommendation 3: Develop viable biofuel/biofuel co-product markets and promote environmentally sound biofuel technologies

Recommendation 4: Coordinate institutional support and develop an innovation system for sustainable biofuel production

Recommendation 5: Base feedstock choices on proper agronomic knowledge

Recommendation 6: Minimize the potential for food-fuel competition

Recommendation 7: Create appropriate land tenure mechanisms

Recommendation 8: Prevent speculative behaviour by biofuel ventures

Recommendation 9: Promote regional biofuel markets

Recommendation 10: Promote bilateral cooperation

Recommendation 11: Include environmental and social concerns in biofuel policies

Recommendation 12: Provide incentives to reduce harmful environmental practices

Recommendation 13: Consider trade-offs and unintended consequences along the full life cycle of biofuel chains

As a final word, we cannot stress enough how important it is for policymakers to understand the national and local context within which biofuel production and use will take place. Understanding this context and the competing interests and trade-offs of biofuel production and use can go a long way toward designing effective biofuel policies.

Keywords: Africa, biofuels, sugarcane ethanol, jatropha biodiesel, ecosystem services, biodiversity, poverty alleviation

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1. Introduction

1.1 Definitions

Biofuels are a type of fuel obtained from solid biomass through chemical or biological processing. Biofuels are mainly developed to substitute conventional transport fuel and secondarily to be used for cooking, lighting and rural electrification/power generation (FAO, 2009; IEA, 2004). Currently, liquid biofuels (e.g. bioethanol and biodiesel) are by far the most widely used biofuel types for transport purposes[1] so for reasons of simplicity for the remainder of the report the term "biofuels" will denote liquid biofuels. Depending on the raw material (feedstock) and conversion technology used, biofuels can be distinguished as first- and second-generation biofuels.[2]

First-generation biofuels are mainly produced from edible plants or animal fats using conventional biochemical technologies.

First-generation ethanol can be obtained from the fermentation of the edible parts of sugar-rich crops such as sugarcane (*Saccharum officianarum*), sugar beet (*Beta vulgaris*) and sweet sorghum (*Sorghum spp.*), or starch-rich crops, such as maize (*Zea mays*), wheat (*Triticum spp.*) and cassava (*Manihot esculenta*) (Fischer et al., 2009). After fermentation and distillation, ethanol can be directly blended with gasoline in different proportions. For example, a mix of 5 per cent ethanol and 95 per cent gasoline is denoted as "E5."

First-generation biodiesel is produced from the trans-esterification of animal fats and vegetable oils. Common plant-derived feedstocks include oil from rapeseed (*Brassica napus*), soybeans (*Glycine max*), sunflower (*Helianthus annuus*), palm (*Elaeis guineensis*) and jatropha (*Jatropha curcas*) (Fischer et al., 2009). Less conventional feedstocks include coconut oil (*Cocos nucifera*), castor bean oil (*Ricinus communis*) and oil from numerous other oil-bearing crops. The fatty acid methyl-esters produced during initial processing[3] can then be blended with conventional diesel in different proportions, for example B5 (5 per cent biodiesel, 95 per cent conventional diesel). In some cases, pure plant oil from oil-bearing crops such as jatropha has been used directly as a fuel for cooking transport and/or power generation purposes (IEA, 2010).

Second-generation biofuels are produced from nonedible plants (e.g. short-rotation coppice, perennial grasses) or from the nonedible parts of food crops (e.g. agricultural and forestry by-products) through the use of relatively advanced technologies (IEA, 2010). Current technologies include the hydrolysis and subsequent fermentation of cellulose, hemicellulose and lignin or gas-to-liquid processing (e.g. Fischer-Tropsch process) (Gupta and Demirbas, 2010).

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[1] Other biomass-derived fuels such as biogas and syngas can also be used for transport purposes. Their current contribution to transport globally is far lower than that of liquid biofuels.

[2] There are also third- and fourth-generation biofuels, produced from algae and genetic optimization of feedstocks respectively, but they are still in the early experimental stage.

[3] Processing varies between feedstocks.

1.2 Biofuel drivers, feedstocks and policies in Africa

1.2.1 Drivers

Brazil has been a pioneer in large-scale biofuel production and use for transport purposes. The first fuel ethanol policies in Brazil were established in the 1930s but it was not until the 1970s energy crises that large-scale ethanol policies were implemented (Puppim de Oliveira, 2002). Due to a number of interconnected factors the Brazilian ethanol programme is generally seen as a success that several other countries in the developed and developing world seek to replicate (Gasparatos et al., 2012a; Fischer et al., 2009). In the past decade the United States (US), the European Union (EU), India, China and several other countries have started implementing policies set to boost biofuel production and use (REN21, 2012).

Since the mid-2000s, there has been a growing interest in biofuel production and use across Africa. This has been due to policy concerns mainly revolving around energy security and economic development. For example, high petroleum prices, fuel insecurity (particularly in the interior of the continent), foreign exchange savings and the potential for economic and rural development have all influenced, in varied degrees, several countries across Africa to consider biofuels as parts of their energy strategies (Gasparatos and Stromberg, 2012). In contrast to some developed countries, environmental concerns such as the reduction of greenhouse gases (GHGs) and the improvement of ambient air quality does not seem to have been a direct driver of biofuel expansion in Sub-Saharan Africa.

A major catalyst of biofuel expansion across Africa has been the perceived potential to export biofuels and feedstock to emerging international biofuel markets. Private firms from OECD and non-OECD countries are acquiring land to develop large-scale biofuel plantations in several African countries (Matondi et al., 2011; Cotula et al., 2008; Nhantumbo and Salomão, 2010; GEXSI, 2008) with the aim of building a biofuel/feedstock production base that can export to the EU biofuel market following the ratification of the EU Renewables Directive 2009/28/EC (EU-RED) (Schut et al., 2010; von Maltitz et al., 2009).

Another international circumstance that seems to have boosted efforts for biofuel expansion in the continent has been the attempt of dominant players in ethanol production, such as Brazil, to make ethanol an internationally traded agricultural commodity (Gasparatos et al., 2012a). For this to happen there neededs to be a diversification of producing countries and a breaking of the current ethanol duopoly between the US and Brazil (Abramovay, 2008). To enable this the Brazilian government has facilitated the transfer of relevant know-how and technology to African countries such as Ghana, Angola, Mozambique and Kenya, an effort branded the "ethanol diplomacy" (Almeida, 2009; Franco et al., 2010). Brazil still dominates global ethanol exports but a number of new bioenergy policies and investment initiatives established in the EU, the US, Japan, Malaysia, Indonesia, South Africa, Colombia, the Philippines and Sub-Saharan Africa are giving momentum to the development of an international ethanol market (Nyberg, 2012).

1.2.2 Feedstocks and policies

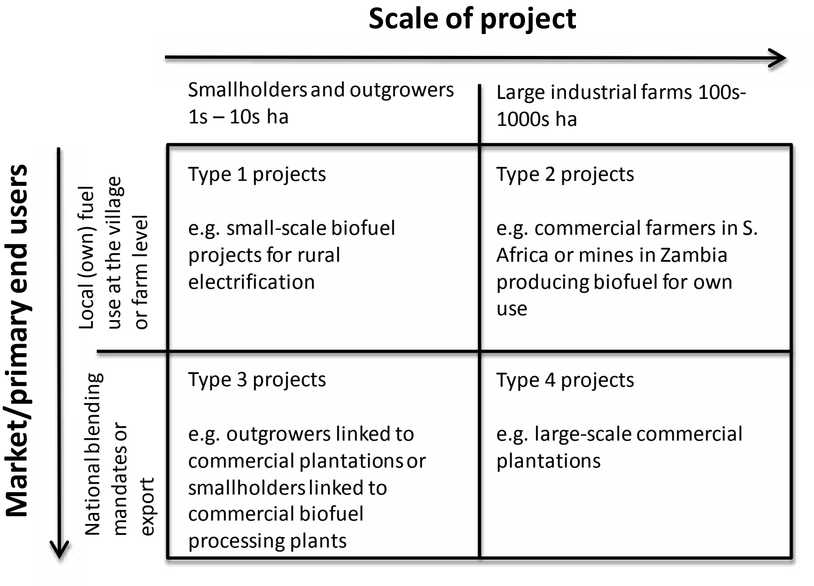
South Africa blended sugarcane ethanol with petrol from the 1920s until the early 1960s when cheap imported fossil fuels made such blending no longer viable (von Maltitz and Brent, 2008). Zimbabwe blended sugarcane molasses ethanol in 1980, followed by Malawi in 1982 and Kenya in 1983 (Batidzirai and Johnson, 2012). In fact, ethanol blending in Malawi reached mixtures of up to 20 per cent at times (E20) (Mitchell, 2011). These early blending programmes aimed to increase national energy security and save foreign exchange by reducing oil imports.

However, the recent interest from foreign investors for biofuel and feedstock production in Africa caught most countries without established policies for promoting and regulating biofuel expansion (Mitchell, 2011). South Africa was the first country to put in place a formal biofuel policy (2007), followed by Mozambique (2009) and Angola (2010) (von Maltitz et al., 2012). Tanzania and Zambia have completed policies, but they have not made them publicly available yet. Lately a number of African countries have also enacted biofuel blending mandates, e.g. Ethiopia (E10), Malawi (E20) and Zambia (E10, B5) (REN21, 2012; Mitchell, 2011).[4]

Jatropha (for biodiesel), sugarcane (for ethanol) and molasses (for ethanol) have been the biofuel feedstocks currently attracting the most interest across Africa and have dominated proposed biofuel investments in the continent (Mitchell, 2011). Other feedstocks such as cassava, palm oil, sweet sorghum, tropical sugarbeets, canola oil and sunflower oil have been identified as promising in different parts of the continent but, to date, their contribution has been much lower (Mitchell, 2011). Despite the relatively large feedstock production potential in the continent (Field et al., 2008; IEA, 2010) there are no plans to pursue second-generation biofuel production in Africa. This is mainly due to the lack of know-how, skilled personnel and appropriate infrastructure (IEA, 2010).

1.3 Modes of production

Depending on the motivation (driver) for feedstock production and the scale of production, four distinct production modes can be identified in Africa (Figure 1).



	Smallholders and outgrowers 1s – 10s ha	Large industrial farms 100s-1000s ha
Local (own) fuel use at the village or farm level	Type 1 projects e.g. small-scale biofuel projects for rural electrification	Type 2 projects e.g. commercial farmers in S. Africa or mines in Zambia producing biofuel for own use
National blending mandates or export	Type 3 projects e.g. outgrowers linked to commercial plantations or smallholders linked to commercial biofuel processing plants	Type 4 projects e.g. large-scale commercial plantations

Figure 1: Typology of biofuel projects in Africa
Source: Adapted from (Haywood et al., 2008; von Maltitz et al., 2012).

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[4] In 2007 South Africa issued E5 and B2 blending mandates that have not been implemented. The Kenyan city of Kisumu has an E10 mandate. Nigeria does not currently have a blending mandate but has a target for E10 (REN21, 2012).

Type 2 and 4 projects entail large-scale feedstock production in large plantations[5] (100s–1,000s ha) either for own fuel use (use within farms) or for commercial purposes (sell feedstock in national and international markets). These are usually large-scale corporations owned by foreign investors or funded through direct foreign investments (von Maltitz et al., 2012). Such large plantations appropriate large areas exclusively for feedstock production, which can in some case compromise or even displace previous land uses. Of the two, Type 4 is by far the most common with numerous large-scale jatropha plantations having been established in Mozambique (Ecomoz, ESV, Sun Biofuels, D1 Oils), Zambia (D1 Oils), Tanzania (D1 Oils, Sun Biofuels[6]), Madagascar (GEM Biofuel Plantations) and other parts of Africa (Schut et al., 2010; von Maltitz and Setzkorn, 2012; von Maltitz et al., 2012; Mitchell, 2011).

Type 1 and 3 projects entail feedstock production by smallholders (1s–10s ha) for local use (use in small-scale biofuel projects) or for commercial purposes (sell as a cash crop). Type 1 projects (small-scale biofuel projects) have been promoted across Africa by nongovernmental organizations (NGOs) and development agencies as as a way to promote rural development and alleviate poverty (FAO, 2009; Energia, 2009). Human well-being benefits from small-scale biofuel projects mainly materialize from the local production and consumption of renewable energy carriers resulting in enhanced local income and/or energy provision (Stromberg and Gasparatos, 2012), Sections 3.4.1 and 3.4.3. Examples include rural electrification projects in Mali, Mozambique and Uganda (from straight jatropha oil) and biodiesel production in South Africa (from sunflower seeds) (FAO, 2009; Energia, 2009). Another similar example is the FACT Foundation project in Mozambique that offered assistance to farmers to grow jatropha in hedgerows for soap-making and pure plant oil which could be used for local power generation (de Jongh and Nielsen, 2011).

Type 3 projects entail feedstock production for commercial purposes by outgrowers linked to large plantations or smallholders linked to feedstock processing plants (von Maltitz et al., 2012). Such an example was Marli Investment's jatropha plantations in Kabwe, Zambia.[7] Marli Investment contracted farmers to allocate half of their 10 ha landholdings, for jatropha production. Marli provided initial inputs and was supposed to provide finance until the jatropha plants started seeding. In return, the farmers were contracted to grow jatropha and harvest the seeds, which they were then contractually obliged to sell to Marli (Haywood et al., 2008; German et al., 2011a).

1.4 Sustainability impacts and institutional setting

Biofuel production and use has been liked to numerous environmental and socioeconomic impacts such as GHG/atmospheric pollutant emissions, increased water use, water pollution, soil erosion, deforestation, biodiversity loss, income/employment generation, energy security, food security, human health and social conflicts (Gasparatos and Stromberg, 2012). Whether these impacts are positive or negative, as well the magnitude of these impacts, depend on a multitude of factors such as the feedstock, the environmental/socioeconomic context of biofuel production, and the policy instruments in place during biofuel production, use, and trade.

Biofuels and their impact on biodiversity have been identified as potentially significant by Multilateral Environmental Agreements (MEAs) such as the Convention on Biological

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[5] In some cases, outgrowers are linked to large plantations.

[6] In 2011 Sun Biofuels ceased operation in Tanzania.

[7] It is not clear if Marli is still operational. Recent reports are that they have abandoned many of their outgrower farmers and have not provided ongoing support nor a market for seeds. Farmers mostly planted much less than 5ha (German et al., 2011a).

Diversity (CBD). Biofuels became a distinct agenda item during the ninth Conference of the Parties (CBD-COP9, Bonn, Decision IX2) and their importance in the CBD process was reaffirmed during CBD-COP10 (Nagoya, 2010). Following CBD-COP10 the Parties were invited to "…develop and implement policies that promote the positive and minimize or avoid the negative impacts of biofuel production and use on biological diversity, and the impacts on biodiversity that affect related socio-economic conditions" (Decision X37) (CBD, 2012).

Legislative instruments such as EU-RED have specified a set of sustainability criteria[8] that has to be met before certain biofuel practices can be widely adopted within the EU (EC, 2009). However, with a few exceptions, legislative instruments usually lack wider environmental and social provisions for biofuel production and use (Gasparatos and Stromberg, 2012). That is particularly true for the countries of Sub-Saharan Africa. Voluntary standards, on the other hand, are promoted by multi-stakeholder alliances and can either target biofuels, e.g. the Roundtable on Sustainable Biofuels (RSB, 2010), or specific feedstocks, e.g. the Roundtable on Sustainable Palm Oil (RSPO, 2007). Usually, such standards are comprehensive in the sense that they encompass a wide range of economic, environmental, and social criteria that have to be met if a biofuel–feedstock practice is to be considered sustainable (Guariguata et al., 2011). However, given their voluntary nature, it currently rests on the biofuel/feedstock producer to certify its product, and the biofuel user to seek a certified product.Even though some legislative instruments such EU-RED require the certification of feedstock/biofuel used within an EU country (but not favouring a specific one), this is not the case for all countries that produce or consume biofuels (Kunen and Chalmers, 2010; Guariguata et al., 2011). This means that non-certified feedstocks/biofuels can be diverted to countries with more lax environmental and social standards. Unless there is a concerted international effort to "demand" biofuel/feedstock certification or to enforce national mandatory biofuel standards, certification on its own might not be sufficient to promote biofuel sustainability (Guariguata et al., 2011). Authors have noted that the potential to export biofuel/feedstock to developed countries (e.g. the EU) can be an opportunity to boost certification efforts in sub-Saharan Africa but also that little progress has been achieved so far (Batidzirai and Johnson, 2012; von Maltitz et al., 2012).

1.5 Aims and objectives

The aim of this report is to identify and discuss the environmental and socioeconomic impacts associated with the two biofuel practices that have attracted the most interest across Africa: jatropha biodiesel (Section 3) and sugarcane/molasses ethanol (Section 4).

We structure the review using the ecosystem services approach (Section 2). In Section 5 we put the main findings of the review into perspective identifying how the ecosystem services provided (or compromised) by biofuel landscapes in Africa can affect human well-being and be agents of poverty alleviation. We conclude by identifying key research gaps at the interface of biofuels and ecosystem services (Section 6) and the main policy-relevant lessons learnt from our review (Section 7).

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[8] e.g. GHG emissions, biodiversity loss, food security, energy security and market profitability.

2. Methodology

The discussions about biofuel sustainability are dominated by a relatively small number of impacts; most notably food security, economic feasibility and GHG emissions. In this report we discuss a much wider array of impacts, as we strongly believe that a piecemeal discussion of biofuel impacts can be easily misunderstood, manipulated and used to support narrow interests (Michalopoulos et al., 2011; Pilgrim and Harvey, 2010).

The biofuel literature is very multidisciplinary and rapidly expanding (Gasparatos et al., 2012b). At the same time there is no consistent way to report findings about the environmental and socioeconomic impacts of biofuels. In this report we employ the Ecosystem Services (ES) framework developed during the Millennium Ecosystem Assessment (MA) as a means of synthesizing in a consistent and comprehensive manner the available evidence about biofuel impacts in Africa.

Ecosystem services are broadly defined as the benefits that humans derive directly and indirectly from ecosystems (MA, 2005a; TEEB, 2010; Fisher et al., 2009; UK NEA, 2012). In a nutshell, the ES approach aims to identify and quantify the contribution of ecosystems to human economy and human well-being.

The starting point of an ES assessment is the identification of the services provided by a given landscapes, or the services compromised in a given area by human activity (MA, 2005a; TEEB, 2010; UK NEA, 2011). Following the MA classification of landscapes services, it has been shown that the main landscapes services associated with biofuel landscapes are: provisioning services (fuel, food, feed, fibre, freshwater), regulating services (air quality regulation, climate regulation, erosion regulation) and potentially cultural services (Gasparatos et al., 2011; Stromberg et al., 2010). Sections 3.2 and 4.2 discuss the current evidence regarding the landscapes services impacted by jatropha and sugarcane biofuel landscapes respectively. The second stage of an ES assessment entails the identification of the mechanisms through which changes in the flows of these landscapes services affect human well-being, either in a positive or a negative manner. Section 3.4 and 4.4 discuss the main human well-being impacts of biofuel landscapes in Africa while Section 5 unravels the mechanisms through which the landscapes services displaced, diverted and degraded by biofuel landscapes affect human well-being. The final stage of an ES assessment is the quantification of these effects. There is a number of different monetary, biophysical and indicator tools that can be used for this purpose (TEEB, 2010). Landscapes service valuation tools have radically different methodologies and assumptions (Gomez-Baggethun et al., 2010) so significant caution is needed when choosing the most appropriate tool if distorted valuations are to be avoided (Gasparatos and Scolobig, 2012; TEEB, 2010). Several studies have been conducted globally to quantify the services provided by different landscapes but to our best knowledge the ecosystem services approach has never been used for biofuel landscapes (Gasparatos et al., 2011; 2012b).

However, according to Gasparatos et al. (2012b) the ES approach offers three very important benefits when studying the socioeconomic and environmental impacts of biofuel production and use.

First, the ES approach employs a systems-perspective, linking ecosystem change and human well-being, two elements of the biofuel debate evoked by supporters and critics of biofuels alike (Gasparatos et al., 2011). The ES approach has been used extensively to study coupled-social ecological systems such as the ones that biofuel production and its use is embedded in. More importantly the ES approach can capture all major drivers and impacts associated with biofuel production and use. Table 1 includes the main sustainability impacts of biofuels as reflected in the certification criteria of the Roundtable on Sustainable Biofuels and other publications (e.g. Hill et al., 2006) alongside the most relevant ecosystem services. Using the ES approach can thus assist biofuel stakeholders to obtain a better grasp of the trade-offs associated with biofuels across different spatial and temporal scales in a robust, yet understandable way. This is something that other current biofuel sustainability assessment frameworks in their current format miss (Gasparatos et al., 2011).

Second, the ES approach is highly transdisciplinary as it can allow the integration of insights from the natural sciences, the social sciences and local knowledge. This methodological pluralism is particularly desirable when dealing with complex and politically charged issues, such as biofuels, as it can offer useful information to a wide spectrum of biofuel actors that usually hold radically different perspectives about biofuel impacts (Michalopoulos et al., 2011; Upham et al., 2011).

Third, the ES approach is widely accepted internationally by academics, practitioners and policymakers. It has matured over the past decade through the efforts of hundreds of scholars and practitioners around the world during large-scale research initiatives such as the Millennium Ecosystem Assessment (MA) and the Economics of Ecosystems and Biodiversity (TEEB). The ES approach has been accepted by the CBD and is a major theme of the forthcoming Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). Several policy initiatives aim to streamline the ES approach in national and international policies (BSR, 2010).

Figure 2 provides a schematic representation of the main drivers, ecosystem services and human well-being impacts associated with biofuels following the MA framework. At this point it should be clarified that since the main starting point of the ES approach is human impact on ecosystems, biofuels can be viewed as agents of ecosystem change. This ecosystem change is a direct consequence of biofuel induced land use change, pollution, agricultural intensification, introduction of alien invasive species and biofuel production and combustion technology. Following the MA vocabulary we collectively refer to the above factors as the direct drivers of biofuel induced ecosystem change. Consequently the drivers of biofuel expansion itself (i.e., energy security, climate change mitigation, rural development) are perceived as the indirect drivers of biofuel induced ecosystem change.

Regarding ecosystem services, the way the academic literature reports the evidence coincides with the typology of ecosystem services used in the MA (see above). However with the exception of "Health" the human well-being impacts of biofuels are not reported following the constituents of human well-being defined in the MA framework. Furthermore in the case of biofuels the constituents of human well-being are highly interlinked. For example, food (a provisioning service) affects virtually all of the MA constituents of human well-being. Following Gasparatos et al. (2011), in this report we discuss the following human well-being categories: rural development, energy security, food security, health and land tenure and social conflicts.

Table 1: Key sustainability issues associated with biofuel production and use from an ES approach perspective

Sustainability issue	**Relevant ecosystem service**	**Main MA constituent of human well-being**
GHG emissions (RSB Principle 3)	Regulating (Climate change regulation)	Basic materials for a good life Security
Rural development (RSB Principle 5)	Provisioning (Fuel)	Security Basic materials for a good life Health
Food production/ security (RSB Principle 6)	Provisioning (Food, feed)	Security Basic materials for a good life Health Good social Relations
Conservation and biodiversity loss (RSB Principle 7)	Biodiversity is not an ecosystem service per se but "*the foundation of ecosystem services to which human wellbeing is ultimately linked*" (MA, 2005b: 18). Services from conserved ecosystems include: Timber and non-timber forest products (provisioning); Clean water (provisioning); Climate change regulation (regulatory) ; Aesthetic and religious values (cultural)	Security Basic materials for a good life Health Good social Relations
Soil (RSB Principle 8)	Regulating (Soil erosion))	Basic materials for a good life
Water (RSB Principle 9)	Provisioning (Freshwater)	Basic materials for a good life Health Good social relations
Air (RSB Principle 10)	Regulating (Air quality regulation)	Basic materials for a good life Security Good social Relations
Health	Provisioning (Food, freshwater) Regulating (Air quality regulation)	Health
Social conflicts (incl. tenure)	Sufficient and equitable supply of provisioning, regulatory and cultural services	Good social Relations
Energy security	Provisioning (Fuel)	Basic materials for a good life Security

Source: Adapted from (Gasparatos et al., 2011).

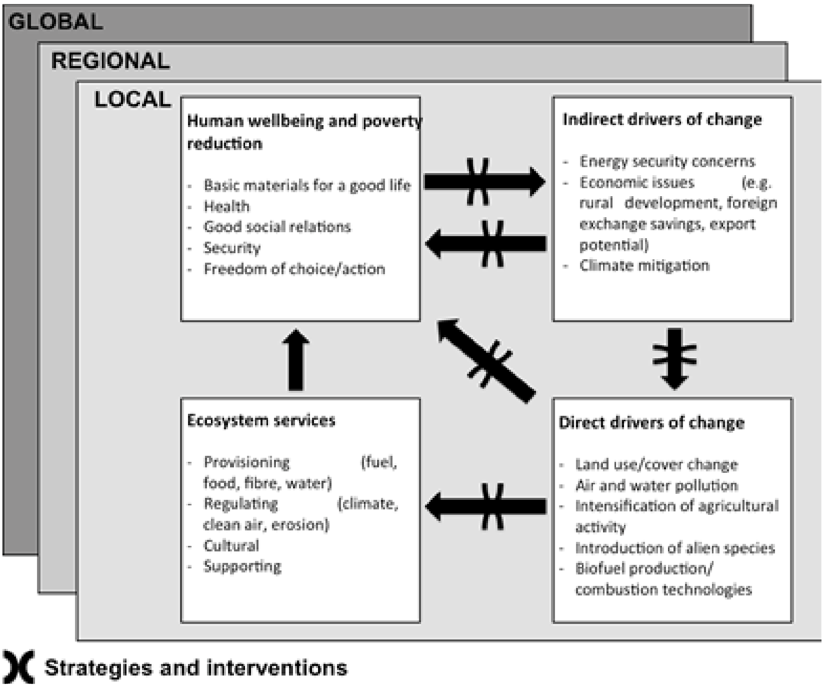

Figure 2: The MA conceptual framework adapted for biofuel production and use. Adapted from (MA, 2005a; Gasparatos et al., 2011).

3. Jatropha biodiesel

3.1 Background and uses

Jatropha is a shrub-like tree that grows 5–7 metres in height. Jatropha originates from Mexico, but now thrives in a number of tropical and sub-tropical regions. It produces seeds with oil content of approximately 35 per cent with the yields of mature plants ranging from 10 g to 4–5 kg/tree/year depending on environmental conditions and management practices (Achten et al., 2008) . It is toxic to humans and animals, (FAO, 2010).

There are numerous documented uses of jatropha including traditional medicine, lighting, soap-making, live-fencing, and support for vanilla plants (Henning, n.d; Jongschaap et al., 2007). However it has been the potential to provide the raw material for biodiesel that has brought jatropha into the limelight.

Jatropha was perceived to provide the silver bullet to many African countries' fuel insecurity. The potential to use jatropha oil as a biodiesel feedstock, together with claims of high yields, drought tolerance, and the ability to grow in dry areas with poor soils, has created huge expectations around jatropha (Heller, 1996; Openshaw, 2000; Achten et al., 2008; Henning, 2000; Henning, n.d.). Currently, with the exception of South Africa (which has banned jatropha Section 3.3), Angola (which is focusing on palm oil), the Democratic Republic of Congo (for which no data is available), and Lesotho (which is climatically unsuitable), all other countries in southern Africa are actively promoting jatropha as their principal biodiesel crop (Lerner et al., 2010). There is also significant interest in other African countries such as Kenya, Tanzania, Senegal, Mali, Burkina Faso and Benin (Romijn and Caniels, 2011; JatroREF, 2012). In fact there have been high expectations for jatropha biodiesel production and use, from industry, farmer associations, NGOs and women and youth groups who wished to reap the multiple economic benefits associated with jatropha (Diaz-Chavez et al., 2010).

In 2008, around 900,000 ha of jatropha was planted globally, of which 760,000 ha was grown in Asia (85 per cent), 120,000 ha in Africa (13 per cent), and 20,000 ha in Latin America (2 per cent) (GEXSI, 2008). Predictions made in the same study suggested that by 2015 jatropha production in Africa alone could reach 2 million hectares. Considering the evidence suggesting that jatropha is drought-hardy and that it can grow in arid environments, the land and technical potential to expand jatropha production in arid and semi-arid areas of Africa might be even higher (Table 2).

Table 2: Land availability and technical potential for jatropha production in semi-arid and arid areas of 8 Sub-Saharan countries

	Botswana	Burkina Faso	Kenya	Mali	Senegal	S. Africa	Tanzania	Zambia
Total area (Mha)								
Semi-arid	44.9	14.3	22.3	24.5	9.7	37.6	31.5	16.0
Arid	12.9	0.5	23.1	39.3	1.5	51.4	0.0	0.0
Other	0	12.4	12.6	61.1	8.3	32.3	61.8	59.0
Excluded areas (Mha), of which	45.4	13.2	39.8	54.9	10.0	87.7	29.6	14.3
Steep slopes	6.0	3.0	19.3	8.4	0.8	62.6	14.5	5.0
Protected areas	18.7	1.8	3.1	2.7	2.8	5.8	6.4	5.3
Biodiversity hotspots	0.0	0.0	11.5	0.0	0.0	17.4	6.0	0.0
Closed canopy forests/wetlands	3.6	0.0	2.2	0.1	0.0	7.4	11.5	4.6
Available area (Mha)								
Arid	3.8	0.0	2.8	5.5	0.5	0.2	0.0	0.0
Semi-arid	8.4	1.6	2.8	3.4	0.7	1.1	1.9	1.7
Share (%)	21.2	10.7	12.4	14.0	10.8	1.5	6.1	10.6
Technical potential (PJ/y)								
Arid	12	0	69	74	9	1	0	0
Semi-arid	190	52	7	92	18	24	50	48
Total final energy consumption in 2006 (PJ/y)	64	NA	495	NA	70	2648	638	241

Source: Adapted from (Wicke et al., 2011).

However, the commercial viability of producing jatropha in arid and semi-arid areas has been questioned. Existing yield data coupled with the recent jatropha yield modeling exercises suggest that in order to obtain economic yields, it will require relatively high rainfall. For example, Trabucco et al. (2010) suggest that the optimum rainfall conditions would be in the order of 1,500 mm/y. Much of the land in countries such as South Africa and Botswana is likely to be too arid for jatropha. As a result, studies such as that of Wicke et al. (2011) might be overestimating the total available land that can support commercially viable jatropha production in southern Africa. On the other hand the more humid areas, which are practically the only ones that have been seriously proposed for jatropha cultivation in countries such as South Africa, have been totally excluded from such analyses.

Low expected yield in arid and semi-arid areas limit to a large extent the capacity to economically produce jatropha on a large-scale in such areas. Currently most jatropha production is occurring in areas of relatively high productivity in order to avoid uneconomic yields (Achten et al., 2010a; Borman et al., 2012; Ariza-Montobbio et al., 2010; FAO, 2010). For example, arable land on abandoned tobacco and cotton plantations (in Mozambique) or savanna ecosystems (in Tanzania) have often been used to grow jatropha (von Maltitz and Setzkorn, 2012). In addition, plantations in Madagascar have reportedly been established on woodlands degraded from timber overharvesting (von Maltitz and Setzkorn, 2012). Existing agricultural areas and ecosystems such as Miombo woodlands and wetter areas of savanna might increasingly be targeted for jatropha expansion in the future (von Maltitz et al., 2012).

3.2 Ecosystem services

3.2.1 Provisioning services

3.2.1.1 Fuel

Feedstock that can be transformed into fuel is the main ecosystem service provided by jatropha landscapes. Trans-esterification of jatropha oil into jatropha methyl-ester and subsequent blending with conventional diesel is the most common practice. Straight jatropha oil is also sometimes used directly in slightly modified engines. Apart from being used for transportation purposes, jatropha derived-fuel can be used for local power generation.

As for any other biofuel, a key consideration when assessing jatropha-derived fuel's viability as an energy resource is the degree to which it provides a net-energy gain. A key indicator of energy viability is the energy return on investment (EROI).[9] Life-cycle analysis (LCA) that takes into consideration the full life cycle of a biofuel[10] has been identified as the appropriate tool for calculating biofuel EROIs (Menichetti and Otto, 2009; Hill et al., 2006; Zah et al., 2007). Table 3 contains energy yields and EROIs reported in different jatropha biodiesel LCAs from around the world.

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[9] EROI is the ratio of the total energy supplied by biofuel combustion to the total energy used during biofuel production. EROIs of higher than 1 denote net-energy provision practices.

[10] The complete life cycle of a biofuel includes several different stages such as feedstock production, feedstock transport, feedstock processing, biofuel production and biofuel distribution/storage/dispensing/combustion.

Table 3: Energy yields and EROIs for jatropha biodiesel

Region	Energy yield (GJ/ton feedstock)	Energy yield (GJ/ha feedstock)	EROI (GJout/ GJin)	Source
Africa	1.43	5.73	4.7	(Ndong et al., 2009)
Africa	9.8	1.38	1.8	(Ndong et al., 2009)
China	11.6	57.9	2.0	(Ou et al., 2009)
China	NA	454.0	1.5	(Wang et al., 2011)
India	NA	NA	1.5-8.6[a]	(Kumar et al., 2012)
India	NA	NA	1.2-7.0[b]	(Kumar et al., 2012)
India	33.0	78.7	1.9	(Whitaker and Heath, 2009)
India	NA	NA	1.8	(Pandey et al., 2011)
India	10.2	17.3	1.4	(Achten et al., 2010)
Thailand	8.3	103.0	1.4	(Prueksakorn and Gheewala, 2008)

Notes:
[a] irrigated scenarios
[b] rain-fed scenarios

Our meta-analysis of jatropha biodiesel LCA studies has shown that in all **reviewed** cases the achieved EROI was higher than 1. In some cases this included the energy gain accruing from the use of co-products. This suggests that jatropha biodiesel can offer net-energy gains, with the biodiesel production stage (transesterification) being the most energy demanding stage of the life cycle (Achten et al., 2008; Reinhardt et al., 2007). Straight jatropha oil LCAs have also reported net-energy gains (e.g., Gmunder et al., 2010). Such results suggest that it makes energetic sense to use directly jatropha oil as a fuel in small-scale biofuel projects without prior processing. However it does not seem to be as energy efficient (lower EROI than jatropha biodiesel) while it may cause malfunction in the combustion engine.

Considering these net-energy gains it can be concluded that jatropha biofuel practices can meet the "net-energy provision" criterion suggested by Hill et al. (2006) and as such be considered to be feasible energy options in the short-to-medium term. However, the achieved EROIs are much lower than those of other biofuels (Section 4.2.1.1) and certainly lower than the EROIs of conventional fossil fuels (fossil fuel EROIs are about 15–20) (Cleveland et al., 2006).

It should be noted that comparing different fuel types or different biofuel applications (see above) on the basis of their EROIs should be performed with caution. For example the technical efficiency of some fuels/applications might be different as manifested by differences in EROI. However the fuels or the applications themselves might be unavailable or otherwise inappropriate due to other negative environmental and socioeconomic factors.

It is also important to consider that energy performance of jatropha biodiesel greatly depends on jatropha yields. Several of the reviewed cases made quite optimistic yield assumptions, possibly overestimating the reported EROIs.

The fuel provided by jatropha landscapes can directly affect access to energy and energy security at multiple scales (household, local, national) (Section 3.4.2). It can also have certain direct and indirect flow-on effects on rural development (Section 3.4.1).

3.2.1.2 Food, fodder and fibre

As a non-food/feed and non-fibrous crop, jatropha does not compete **directly** with provisioning ecosystem services such as food, fodder and fibre. In other words as jatropha cannot be used for food, feed or fibre purposes, using jatropha as a fuel does not divert the crop from such uses as is the case for other food crop-based first-generation biofuels (e.g. maize/sugarcane ethanol or palm oil biodiesel). However it can compete **indirectly** with such provisioning services through competition for land, labour and water resources (Sano et al., 2012).

Regarding competition for land, there have been reports of jatropha-related displacement of smallholder agricultural activities by large-scale biofuel plantations (Bergius, 2012; Cotula et al., 2008; Schoneveld et al., 2011). Such land displacements might have forced smallholders to relocate food production in areas with less favorable conditions (Sulle and Nelson, 2009). There are cases, though, that smallholders have been aware of this indirect competition with food production. In some cases farmers have acted conservatively when planting jatropha in order not to impact their food production. In Zambia, for example, despite suggestions that farmers should allocate 5 ha of their land to jatropha, most farmers only allocated 2 ha or less (Haywood et al., 2008; German et al., 2011a). In Mozambique farmers associated with the FACT Foundation projects have tended to grow jatropha in hedgerows on field boundaries rather than plant Jatropha in fields (de Jongh and Nielsen, 2011; Nielsen et al., 2011).

However, it is the diversion of labour from smallholder or subsistence agricultural production to paid labour in large-scale biofuel projects that is likely to have an even greater impact on the competition between feedstock production and other provisioning services. Crop calendar assessments also suggest that competition for labour may be a limiting factor in households that maintain large areas for both jatropha and food crops (Haywood et al., 2008). At present jatropha projects are not yet fully established and the potential returns to labour are poorly understood (Section 3.4.1.1). As a result the profitability of jatropha will likely influence the extent to which farmers switch from food/fibre to fuel production and as a result the extent of indirect competition between jatropha and other provisioning services.

Even though jatropha is a relatively modest water user, jatropha yields depend greatly on water (Sections 3.1 and 3.2.1.3). As a result, the extent of water-related indirect competition between jatropha and food/feed/fibre will depend on the jatropha yields actually aiming for. Such competition might manifest more severely in irrigated areas than in areas with rain-fed jatropha and food/feed/fibre production.

The above suggest that provisioning service tradeoffs in jatropha landscapes are likely to be complex, with potentially non-obvious feedbacks that can be positive or negative depending on the environmental and socioeconomic context of jatropha production. In some cases these tradeoffs can manifest in different spatial scales (e.g. household, local or national) and have significant impacts on food security (Section 2.4.3) and income generation (Section 2.4.1).

3.2.1.3 Water

Biofuel production (jatropha biodiesel included) can affect freshwater services either through their overexploitation or their degradation (Gasparatos et al., 2011).

Studies have shown that jatropha is a conservative water user due to its high transpiration efficiency (Maes et al., 2009a; Achten et al., 2010c; Everson et al., 2012). Field experiments in South Africa have suggested that jatropha is indeed unlikely to compete for scarce water resources as it is a conservative water user when compared to dry land pastures, deciduous indigenous vegetation and exotic plantation forestry species such as eucalyptus (Gush, 2008; Everson et al., 2012; von Maltitz et al., 2012).

However there seems to be a relationship between water use and achieved jatropha yields. It is suggested that even though jatropha can be grown in arid and semi-arid areas, higher yields can be achieved in wetter conditions (Trabucco et al., 2010). That has been the case in parts of India where higher jatropha survival rates and yields were reported in irrigated jatropha plantations rather than rain-fed plots (Ariza-Montobbio and Lele, 2010).

To the authors best knowledge there have not been any studies about the degradation of freshwater services from fertilizer/pesticide use during jatropha cultivation or from effluent emission during jatropha oil extraction and biodiesel production (Gasparatos et al., 2011), see Section 4.2.1.3.

3.2.1.4 Other provisioning services

Apart from fuel feedstock, jatropha can be used to produce other good/commodities such as soap, fertilizer and solid fuel. With the exception of soap, the contribution of such alternative provisioning services on human well-being has been rather limited for the time being.

Jatropha oil has been commonly used for soap-making in several parts of Africa, particularly in West Africa (Henning, 2009; Schut et al., 2011). It has been found that the economic returns from soap-making are far higher than the sale of jatropha seed for biodiesel production (Schut et al., 2011). As a result it has been suggested that small-scale jatropha projects focusing on soap production would be a better income generation activity than growing jatropha for fuel (Shumba et al., 2011; Schut et al., 2011).

Jatropha seedcake has a high nutrient content and can be used as a fertilizer. Experiments have shown that its use can enhance food crop production, having the additional benefits of an insecticide and molluscicide (Achten et al., 2008; FAO, 2010). However, seedcake needs to be collected from factories and then be redistributed, which could make its use as fertilizer costly. Seedcake made into briquettes may also be used as cooking fuel, but its combustion produces too much smoke (FAO, 2010). There do not seem to be detrimental health effects when using jatropha seedcake as a fertilizer (van Eijck et al., 2010) but burning jatropha seedcake briquettes as a fuel might affect human health (Section 3.4.4).[11]

Latex, leaves and oil from jatropha reportedly have medicinal properties, for treating wounds (in India) and inducing diarrhea (in Kenya) (Boerstler, 2010). Several publications indicate that the curcin in the Jatropha oil has anti-tumour effects (Lin et al., 2003; Luo et al., 2006; Prajapati and Prajapati, 2005 as quoted in Boerstler 2010). Soap made from jatropha oil has been credited with health benefits, though this property seems to be largely anecdotal

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[11] As a result it might be more sensible to use the jatropha seedcake briquettes for biogas production rather than direct combustion.

(Boerstler, 2010; Wahl et al., 2009). Very small plantations or individual trees could meet such medicinal needs.

3.2.2 Regulating services

3.2.2.1 Climate change regulation

Biofuels have been identified as potential climate change mitigation strategies (IPCC, 2007). Several jatropha LCAs have shown that jatropha biodiesel can emit less GHGs during its entire life cycle than conventional diesel. Table 4 contains emissions (in grams of CO_2 equivalents emitted during the production of 1 MJ of jatropha biodiesel) and the percentage emissions saving it represents when compared to the life-cycle emissions of conventional diesel. In some cases it would appear that the GHG emission savings of jatropha biodiesel are considerable.

Table 4: Emissions and emission savings for jatropha biodiesel

Region	Emissions (g CO_2eq/MJ)	Emission savings (%)	Source
Africa	23.5	72%	(Ndong et al., 2009)
Africa	74.5	11%	(Ndong et al., 2009)
Brazil	40.0	55%	(Bailis and Baka, 2010)
China	17.9	80%	(Hou et al., 2011)
China	52.0	49%	(Ou et al., 2009)
India	74.6	85%	(Gmunder et al., 2010)
India	NA	50-107%[a]	(Kumar et al., 2012)
India	NA	40-93%[b]	(Kumar et al., 2012)
India	NA	69%	(Pandley et al., 2011)
India	123.7	55%	(Achten et al., 2010)
Global	50	51%	(Almeida et al., 2011)

Notes:
[a] irrigated scenarios
[b] rain-fed scenarios

Jatropha GHG savings are relatively higher than those estimated for other first-generation practices such as maize/wheat/ethanol and most first-generation biodiesel practices (Menichetti and Otto, 2009). This is mainly because jatropha is a perennial crop. As a result it has lower nitrogen-fertilization requirements requiring less fertilizers, while it conserves soil carbon through annual belowground production and decay (von Maltitz et al., 2012).

The above suggest that jatropha landscapes can indeed provide important climate mitigation services in Africa and beyond. It is interesting to note that even though most African countries have not pursued biofuel production as a mitigation strategy (Section 1.2), jatropha-derived fuel combustion in Africa can provide considerable climate regulation services as a co-benefit.

However it is important to consider that several of the **reviewed** LCAs relied heavily on optimistic jatropha yields (Section 3.2.1.1) which might have overestimated the climate regulation services provided by jatropha landscapes.

Most importantly most of these LCAs did not account for the impact of Land Use and Cover Change (LUCC) on GHG emission. Biofuel studies that have considered LUCC effects have shown that carbon loss from soils can release significant amounts of GHGs, creating carbon debts that might take several decades to repay (Fargione et al., 2008; Searchinger et al., 2008).

For example, one of the few jatropha studies that has accounted for LUCC effects has shown that if LUCC is not considered, then jatropha biodiesel in Brazil can emit 55 per cent less GHGs than conventional diesel. However, if jatropha is grown on shrubland then jatropha biodiesel emits 59 per cent more GHGs than conventional diesel (Bailis and Baka, 2010).

Recent research in Africa has shown that jatropha production can also produce significant carbon debts if it is established in virgin Miombo woodland. Romijn (2011) calculated a 33-year carbon debt, which might be a conservative estimate as the carbon released from the decaying Miombo root system and left into the plantation soil was not considered. Achten and Verchot (2011) calculated that jatropha projects in parts of Ghana and Zambia can result in carbon debts that can take as much as 94 and 188 years respectively to repay. Finally von Maltitz et al. (2012) using the Century ecosystems model calculated carbon repayment times of 17–36 years from converted savannas (Skukuza, S. Africa) and 32–81 years from converted Miombo woodland (Mongu, Zambia), Figure 3.

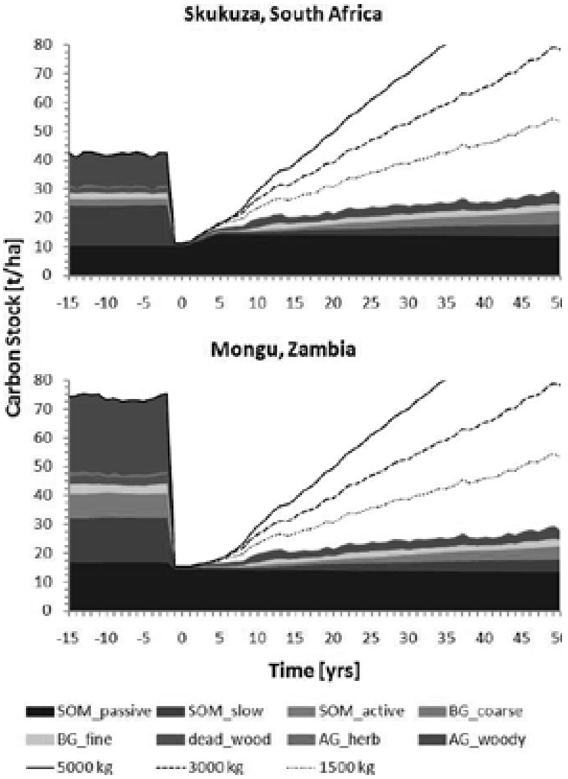

Figure 3. Net-carbon balances and repayment times of jatropha biodiesel production in semiarid savannah (Skukuza, S. Africa) and Miombo woodland (Mongu, Zambia). Source (von Maltitz et al., 2012).

Note: The black lines indicate the net carbon balance for different yield scenarios (kg/yr).

3.2.2.2 Air quality regulation

To the authors best knowledge there are no LCAs that have calculated the emission of atmospheric pollutants from jatropha-derived transport fuels.

Other studies have shown that the combustion of jatropha and tobacco briquettes emits higher quantities of polycyclic aromatic hydrocarbons (PAHs) (23–67 times), hydrocarbons (2 times), NOx (3–5 times) and soot (4–13 times) than the Malawi charcoal reference (Hamoen et al., 2011). On the other hand, the combustion of liquid jatropha fuels used in lamps emits less PAHs (240 times), CO_2 (3 times) and soot (1.5 times) than standard paraffin. However the production of NOx (5 times), CO (2 times) and hydrocarbons (7 times) is higher than standard paraffin (Hamoen et al., 2011).

3.2.2.3 Erosion regulation

As a tree species, jatropha does not need to be planted annually. This suggests a lower overall time of bare/exposed soils due to harvesting and regrowth than annual or perennial crops.

Jatropha has been used for erosion control and rehabilitation with the justification that the root system may help binding the soil (Keravina et al., 2011). However, no reports could be found verifying or quantifying the soil quality and erosion control benefits of jatropha.

Jatropha has been used extensively throughout Africa as a hedge species to limit livestock movement (Nielsen et al., 2011; Achten et al., 2008). Its relatively rapid growth, unpalitiability to livestock and the fact that it can be easily established from either seed or truncheons makes it well suited to this application. As such it can be used both to protect fields from livestock as well as stabilize contour bunds (Achten et al., 2008).

3.2.3 Cultural services

There is hardly any research connecting jatropha production and cultural ecosystem services. Land in Africa, can have important spiritual and social values, so purely economic calculations are unlikely to capture local perceptions about proposed land deals involving jatropha expansion (von Maltitz et al., 2012). For local communities and indigenous people such services frequently form an important element of their culture and can be threatened (MA, 2005a).

Marginal land in Africa is often used by communities, which have informal rights over its use (Section 3.4.5). Such marginal land often provides other ecosystem services not always being acknowledged when assessing the costs and benefits of biofuel production (Dale et al., 2010).

Even if jatropha projects are established on marginal land there can be an impact on the value that local communities derive from this land through mechanisms such as habitat destruction (Section 3.3) and displacement of traditional crops (Section 3.2.1.2). Reducing these trade-offs by mixed use of the landscape can be possible to an extent through intercropping jatropha with traditional crops. However evidence suggests that higher jatropha yields are achieved when other vegetation is cleared (Everson et al., 2012; Section 3.4.3). More importantly mix use might not even be possible for some cultural ecosystem services such as recreation and ecotourism. As some natural habitats in Africa are highly valued for eco-tourism, potential conversion of these natural habitats for jatropha production, particularly large-scale jatropha projects (Section 3.3) may affect negatively such cultural services, though no research has yet identified or quantified such effects.

Invasive plant species may compete with, and eventually eliminate, traditional plant species with high cultural value. This can potentially have severe impacts especially for the poor in tropical countries (MA, 2005b). Even though jatropha has been associated with invasive behaviour (Section 3.3) the extent to which it can compromise such cultural ecosystem services has not been assessed in the African context.

3.3 Biodiversity

The impact of jatropha production on biodiversity in Africa (and elsewhere) has been very poorly studied. Large-scale jatropha production entailing extensive monocultures (Section 1.3) might be particularly hostile to biodiversity as is the case for other biofuel feedstocks grown in extensive monocultures such as oil palm, soybeans, maize, sugarcane and rapeseed (e.g., Fischer et al., 2009; Fitzherbert et al., 2008; Groom et al., 2008; Tilman et al., 2006). In the absence of this evidence, the discussion about jatropha's impact on biodiversity and how to minimize it, can benefit significantly from the ongoing discussions about the impacts of other feedstocks.

To the authors' best knowledge there have not been any biodiversity surveys conducted in jatropha landscapes in Africa or elsewhere. As a result our knowledge about species occurrence in jatropha landscapes and surrounding ecosystems is very incomplete. It is impossible at this point to directly ascertain the impact of jatropha landscapes on biodiversity although replacing Miombo woodlands or savanna with jatropha plantations will definitely have an impact on local, and possibly regional, biodiversity and ecosystem processes..

It has been suggested that jatropha's biodiversity impacts might depend on the production system adopted and the original land use (Blanchard et al., 2011). Jatropha cultivation can result in four types of land use change (von Maltitz and Brent, 2008):

- conversion of existing agricultural land;
- conversion of abandoned agricultural land;
- conversion of degraded lands;
- conversion of natural vegetation.

Each of these four LUCC types is likely to have varying biodiversity impacts, with the conversion of natural habitats having the most severe impacts (von Maltitz et al., 2010). Potential related biodiversity impacts from large-scale forestry expansion in the Eastern Cape (South Africa) have been modeled using the Biodiversity Intactness Index (BII), Figure 4. Even though this exercise is not jatropha-specific, it can be used to infer how LUCC effects from large-scale jatropha expansion might affect biodiversity in the region.

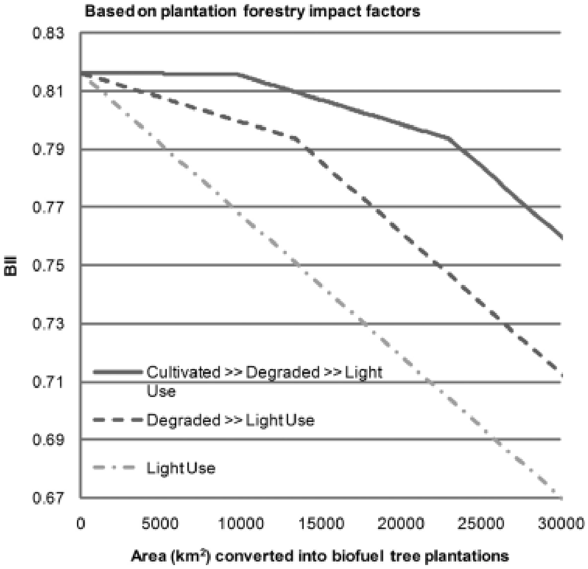

Figure 4. Influence of LUCC effects on the BII for tree biofuel crops, Eastern Cape (South Africa)
Source: (von Maltitz et al., 2010).

Figure 4 suggests that the BII will decrease more rapidly when relatively undisturbed ecosystems (light use) are converted to jatropha, when compared to conversion of degraded lands, areas under cultivation or mixed-type landscapes.

In some Miombo areas, tree clearing has occurred when establishing jatropha plantations (Romijn, 2011). Such direct LUCC effects can result in loss of natural vegetation and can be a feature of both large-scale biofuel projects (Type 4 projects, Figure 1) and smallholder based feedstock production (Type 3 projects, Figure 1). Regarding the latter German et al. (2011a) suggest that in their case area in Zambia, for each 1,000 ha of jatropha grown by smallholders, 438 ha of mature forest could be cleared. Another example is the case of Bioshape. Bioshape was a large-scale jatropha project that was envisaged to occupy 31,000 ha at the highly biodiverse Kilwa region in Tanzania. Even though less than 1,000 ha were cultivated before the project filing for bankruptcy, there were fears that it would have resulted in significant deforestation (WWF-TPO, 2009).[12] In both these cases the conversion of native forests into jatropha landscapes could have had potentially important impacts on biodiversity. It should be mentioned that while we were preparing this report we came across other allegations of jatropha-related deforestation. However it was very difficult to ascertain the scale and impact of such effects as there is very little peer-reviewed literature (e.g. van Eijck et al., 2010).

However most companies associated with jatropha production seem to be reluctant to plant jatropha on forest or woodland[13], and in many instances developers have targeted degraded, fallow or abandoned lands (von Maltitz and Setzkorn, 2012). For example GEM

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[12] There were allegations that the Environmental Impact Assessment produced by this project was flawed, failing to mention that the project would eventually span within a highly biodiverse coastal forest (WWF-TPO, 2009: 87)

[13] Perhaps due to the strong emphasis on avoiding deforestation included in some biofuel policies (e.g. EU-RED, 2009/81/EC) and biofuel certification schemes (RSB, 2010).

biofuel Plantations in Madagascar plant Jatropha directly into degraded savannas[14] or grassland (von Maltitz et al., 2010). A potential unintended consequence of this direct LUCC effect is that plantations will be established on grasslands, a vegetation type that is both rich in biodiversity and under extreme threat (Gibbs Russell, 1986; Mucina and Rutherford, 2006; O'Connor and Bredenkamp, 1997).

Apart from directly clearing land, jatropha plantations can displace agricultural activities or the harvesting of other ecosystem services (e.g. wild food, timber, fuelwood, non-timber forest products) into new areas (e.g. Section 3.4.1 and 3.4.3). This might result in new land being cleared to host the displaced agricultural activities or in the overexploitation of specific species for obtaining services such as timber or wild-food. Such indirect LUCC effects and their biodiversity impacts have been even less studied for jatropha landscapes.

Management practices applied within jatropha plantations are also expected to have biodiversity impacts. For example, species choice and planting configuration in large-scale jatropha plantations can influence landscape heterogeneity (von Maltitz et al., 2012). It has also been found that jatropha yields increase if grass vegetation is cleared between jatropha trees (Everson et al., 2012) which suggests potential biodiversity decline in jatropha plantation if the grass is cleared for attaining higher yields.

Finally, jatropha has been associated with invasive behaviour in certain parts of Australia (FAO, 2010). Its invasiveness is still uncertain in the African context, as there is sometimes a lag between species introduction and the manifestation of invasive behaviour (Krivanek et al., 2006). For this reason South Africa has chosen to adopt a precautionary stance and ban jatropha cultivation within the country. This approach can be, to a large extent, justified considering the high control cost of other (non-jatropha) related invasive specie in the African context such as eucalyptus, which can potentially negate the initial benefits from the specie's introduction (Le Maitre et al., 2002; Turpie and Heydenrych, 2000). On the other hand most other African countries have chosen to allow jatropha cultivation (Section 3.1).

3.4 Human well-being

3.4.1 Rural development

The jatropha sector has attracted significant interest in Sub-Saharan Africa by foreign investors (GEXSI, 2008). Stakeholders in Africa (and beyond) have perceived jatropha as having the potential to boost economic growth and exports, while at the same time boosting rural development and poverty alleviation (Arndt et al., 2010; 2011).

Stimulating investment interest in the ailing agricultural sector and increasing employment and income opportunities are key cornerstones of this vision. However, different modes of jatropha production (Figure 1) have different objectives and different beneficiaries at different scales (household, local, national, international). As a result the effect of jatropha production on employment and income generation can be varied.

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[14] Even though there are no studies, degraded grasslands may still maintain more biodiversity than jatropha plantations. A lot will depend on the degree of degradation and the type of management, and particularly how the understory of the jatropha plantation is managed. For example, some jatropha projects pit plant within the existing grassland, but many other projects completely clear the herbaceous layer.

3.4.1.1 Impact on employment

Jatropha production and use can provide employment opportunities through:

- direct employment at jatropha plantations (Type 4 projects, Figure 1);
- contracted supply of jatropha seeds to jatropha oil companies (by smallholders) (Type 3 projects, Figure 1);
- training and up-skilling activities;
- new business opportunities through rural electrification (small-scale biofuel projects, Type 1 projects, Figure 1).

The first three, are essentially **direct** employment generation mechanisms, while the fourth is a rather **indirect** mechanism.

Direct employment and contracted production of jatropha seeds

Most jatropha plantations across Africa have not reached maturity as they were established relatively recently. As a result the evidence related to local employment generation has, up to now, been largely limited to the plantation establishment phase. Employment impacts during the maintenance phase are less clear but it is likely that much of the generated employment will be seasonal, rather than permanent (German et al., 2011a; Schut et al., 2011).

This means that it is quite difficult to obtain reliable information about the labour opportunities that will arise in the long term at the regional level. Available estimates suggest that the number of new jobs created is fairly low. Some company estimates in Mozambique suggest the creation of 0.14–0.17 jobs per ha estate (Schut et al., 2010). Huicoma/Tomota in Mali claimed to be employing 1,000 local labourers across its 100,000 ha estate in Office du Niger, which is as low as one person per 100 ha (Oakland Institute, 2011). However the scope might exist to employ more local labour. For example, based on data reported by UN DESA (2007), it takes 1.5hrs to collect 5kg of jatropha seeds for the production of 1L jatropha oil. Assuming yields of 2000kg/ha/year this would require a labourer to work 164 hours per day over a year to collect the jatropha seeds from 100ha. In any case it should be mentioned that employment estimates provided by large companies have often not been eventuated (Box 1, Section 3.4.1.2).

Furthermore, few studies have examined economy-wide (national scale) employment impacts associated with jatropha. A general equilibrium model of the national economy of Mozambique suggested that biofuel production could have a significant positive effect on the national economy contributing approximately 0.37 per cent to national gross domestic product (GDP), while generating 271,000 rural jobs (Arndt et al., 2010).[15] In this exercise jatropha had a far higher pro-poor impact when compared to sugarcane ethanol.

An important concern regarding the employment generation potential of large-scale jatropha projects in southern Africa has been the recent problems faced by several firms in the region such as D1 oil, SUN Biofuel, ESV and Bioshape (Section 3.3 and 3.4.1.2). For example, SUN Biofuels began its operations in Tanzania with promises of generating thousands of jobs and minimum wage for local villages, but as the project advanced the costs were too high to ensure project viability (Habib-Mintz, 2010). Eventually SUN Biofuels

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[15] The model assumed a 0.33 labourers/ha yield which is a relatively optimistic (but probably more realistic than company estimates) and 3 ha/labourer on small-scale plantations, (compared to the industry's estimate of 0.14-0.17 labourers/ha on large-scale plantations) so the overall employment benefit might have been inflated (Schut et al., 2010).

closed down in 2011 leaving hundreds of people unemployed. Other large-scale jatropha projects have also either fully closed or have encountered financial difficulties and have been sold out to new investors. This has affected significantly employment opportunities. In at least one instance labourers were left without pay for over a year (von Maltitz et al., 2012) while in another instance more than 90 per cent of the labour force was retrenched (Carrington et al., 2011).

The demise of these companies has in part been due to unexpected time delays in achieving the first jatropha yields as well as indications that yields were substantially lower than those assumed during project planning. This impact was compounded by the global recession of 2008 that caused investors to withdraw investments (von Maltitz et al., 2012; Mitchell, 2011).

Due to these reasons, the number of jobs being eventually generated (and the wages offered) by large-scale investors has, in several cases, been far lower than initial community expectations (Bergius, 2012; Carrington et al., 2011).

Labor training and up-skilling

Jatropha-related employment benefits can also be gained through the investment into a country's research capacity and labour force up-skilling. For example, training can be provided to technicians to operate generators and manage jatropha plantations. UDSM in Tanzania is building domestic R&D capacity, by creating a research-only facility for biodiesel from vegetable oils, and biodiesel and bioethanol for transport (GTZ, 2005). The Mali Biocarburant (MBSA) recruited and trained over 2,800 farmers in Mali for Jatropha production, through a Farmer Business School outreach network (Basinger et al., 2012).

New business opportunities through rural electrification

The rural electrification MFC Mali Garalo project is one of the most successful examples in Africa of employment benefits obtained from a jatropha-based energy system. The project was initiated in 2007 with jatropha seedling planting and preparation of the generator. By 2011 the generator was fully operational using jatropha. The rural electrification project provided electricity to 350 homes, roughly 50% of the Garalo village. More crucially it also provided electricity to local small business and streetlights, which helped stimulate the local economy, e.g. electricity sewing machine, powered tools for furniture makers, and training technicians (Gilbert, 2011).[16]

KAKUTE in Tanzania ran a trial jatropha farm across 25 hectares for rural electrification, while its sister company, JPTL, manages jatropha products including oil, soap, biogas stoves from jatropha presscake, and pressing machines benefiting 2700 small producers (GTZ 2005; Shackleton and Gumbo, 2010). There have been further reports of companies interested in initiating biogas production from jatropha seedcake. For example, Pegasus, a jatropha company in Uganda, is yet to begin jatropha oil production but have preliminary plans to build a biomass digester to combust jatropha seedcake for biogas and electricity generation (Pegasus, 2012, pers. comm., 16 March). However, to our best knowledge there has not been any substantial study quantifying the cost-effectiveness and expected benefits of jatropha seedcake biogas production.

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[16] A cost-recovery pricing system for electricity was also designed to allow self-sufficiency. However input and operational expenditures are not fully covered by electricity charges and require the support of the NGO.

3.4.1.2 Impact on income

There are three **direct** mechanisms through which jatropha production can generate income for rural households and as such become an agent of poverty alleviation:

- income to individuals engaged as salaried workers in jatropha plantations;
- income to smallholder farmers producing jatropha as a "cash crop" for sale;
- income to smallholder farmers growing jatropha for uses other than biofuel feedstock.

Furthermore, rural electrification with jatropha-based fuel can **indirectly** boost income opportunities through the development of generally higher-paid manufacturing and service jobs (Section 3.4.1.1). However, there can also be potential negative impacts on income through the displacement of previous income opportunities or through inflationary pressures on locally produced food and fuel.

Income from salaried work in jatropha plantations

As a rule of thumb, salaried work in large-scale plantations has been equally, or even better, remunerated than other agricultural activities in Africa (von Maltitz et al., 2012; Smeets, 2008). Since many rural areas in Africa have very limited job opportunities even low-waged jobs are highly sought after. In some parts of Africa (e.g. Brong Ahafo region, Ghana) the high income obtained through salaried work in jatropha plantations influenced rural households to abandon other off-farm income activities (Schoneveld et al., 2011).

However, even though biofuel projects typically offer salaries that are higher than prevailing agricultural rates (von Maltitz et al., 2012; Smeets, 2008), in global terms the wages tend to be very low and when divided across a household are less than USD 1 per day. For example it has been reported that workers in some jatropha plantations in Mozambique can earn as little as EUR 44 per month (Mota, 2009). Totoma in Mali currently pays its plantation workers between CFA 500–750 (approx. USD 1–1.50) per day (Oakland Institute, 2011). This wage is the legal minimum wage requirement in Mali, but considering that Tomota only employs around one person per 100 ha, few will benefit from the plantation's minimum wages. A very good example that shows the relatively low impact of the income offered by jatropha plantations on local poverty alleviation, is the case of SUN Biofuels in Tanzania (Box 1).

Box 1: Direct and indirect impacts of a jatropha plantation on income generation.

SUN Biofuels started its venture in Tanzania among high hopes of employment and income generation. The company initially announced that it would create 1,000–4,000 jobs for each village participating in the project, paying USD 1,095 per person per year (Habib-Mintz, 2010).

As the project progressed it became obvious that the promised wages could not be attained since jatropha oil was not as profitable as initially expected (Romijn and Caniels, 2011). The company ended up paying workers only GBP 42 per month which was considered as insufficient by these workers to compensate for their lost ability to farm (Carrington, 2011; Cohen, 2011). In 2011 the company ceased its operation in Tanzania due to concerns over the economic viability of the project.

It is now understood that even when discounting for the eventual collapse of the project, community members may have been worse off from an income perspective even from the early stages of the project. Even though the project provided hundreds of salaried jobs it also displaced access to many other provisioning ecosystem services such as fuelwood, charcoal, building material, wild fruits and meat that the community could obtain from the land ceded to SUN Biofuels (Bergius, 2012). Furthermore, it increased the distance required to obtain water and fuel, while at the same time it reduced the time that could be allocated on other activities. This had among others, an inflationary impact on charcoal cost.

Taking all of the above into account, Bergius (2012) suggests that overall the communities involved in this project eventually became financially worse off. Similar conclusions have been reached and for areas in Ghana where the income generated through jatropha-related activities cannot offset losses from other income sources (Schoeneveld et al., 2011).

In summary, studies suggest that the profitability of jatropha production can be fairly variable with small profit margins, largely dependent on the price of the oil received and the cost of labour for harvesting and treating jatropha seeds (e.g. de-husking, crushing) (Ariza-Montobbio et al., 2010; Borman et al., 2012; Wahl et al., 2009). As a result labour costs are a key determinant of jatropha profitability in large plantations.[17] The above suggest that in order to ensure the economic viability of large projects, either lower prices need to be paid for seeds and labour or an increase in seed harvested per hour needs to be attained. In any case this will most likely disadvantage smallholders and plantation labourers either through reduced wages or through reduced employment opportunities due to increased mechanization for jatropha seed de-husking, crushing and potentially harvesting in the long-term.

UN DESA (2007) calculated hypothetical profits per working hour for different levels of mechanization during jatropha oil production in Tanzania, based on agronomic data from Henning (2009). The profit from jatropha oil extracted using a hand press was USD 0.14 per hour, assuming labour costs below the minimum wage of TZS 2,692.5 per day (around USD 1–2 per day). At minimum wage, hand-pressed jatropha oil becomes economically unviable. Using an oil expeller, profit increases to USD 0.24 per hour, taking into account all input costs and assuming minimum wage. If labour cost is around USD 3 per day, then jatropha oil production costs will increase by 90 per cent (Wiskerke et al., 2010).

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[17] High petroleum prices are another factor affecting profitability. High petroleum prices in rural Zambia coupled with relatively cheap labour should make this one of the most economically viable areas for the production of locally used fuel (Borman et al., 2012).

Income from producing jatropha as a cash crop

Due to jatropha industry's immaturity and the, as yet, mainly hypothetical magnitude of yields (Section 3.2.1.1), smallholder farmers take considerable risks by converting their entire cash crop production into jatropha.

As one might expect major determinants of the income that smallholders derive from jatropha are jatropha seed prices and yields. As it is discussed throughout this report jatropha yields can depend on several climatic factors and management practices and in most cases yields have been much lower than initially anticipated. Wahl et al. (2009) using a cost-benefit analysis found that jatropha growing in northern Tanzania has a negative net present value (NPV) for yields less than 2,000 kg / ha / year and only a marginal positive NPV for yields of 3,000 kg / ha / year. Jatropha seed prices in northern Tanzania tripled in between 2005 and 2008. By 2008, the seed price ranged between TZS 180–500 in remote areas driven by demand for seeds for planting and producing seedlings (FAO, 2010). Based on the range of seed prices, gross margin calculation showed poor returns to small-scale producers—with at most 23 per cent profit margin. Oil extraction is more profitable if seeds are acquired at a low price and can increase gross margin to 58 per cent (FAO, 2010).

To make matters more complicated, markets for jatropha seeds are still poorly developed in the region. This has resulted in some cases smallholder farmers finding it difficult to sell their produce, even when linked by contract to large industries. There are instances of farmers spending their savings and time on jatropha cultivation, but eventually being left stranded with unmet expectations, converted land and a trouble finding a market for their jatropha seeds (Hunsberger, 2010). For example, Schut et al. (2011) reports the case of a household in Mozambique that could not find an organized jatropha market, so it could not sell the seeds it produced. Farmers in Zambia, Tanzania, and Mozambique (excluding those linked to the FACT Foundation) have also reported that it is difficult to find markets for seeds, even when linked by contract to the local industries (German et al., 2011a; 2011b).

Where markets are available they are often paying below what the farmers expected (German et al., 2011a; Haywood et al., 2008; Schut et al., 2010). For example, large buyers, such as Diligent in Tanzania, provide a relatively secure market for outgrowers, guaranteeing TZS 150 per kg of jatropha seeds for 10 years (WWF-TPO, 2009). However, this is considered a very low minimum price for jatropha seeds (WWF-TPO, 2009). The FACT foundation in Mozambique reported that farmers were reluctant to sell their seeds at the rate FACT could offer based on the market value[18] as they were able to sell seeds for higher value in Tanzania where there was an inflated value on seeds due to the rush to establish new plantations (Nielsen, 2011).

The above suggest that existence (and maturity) of jatropha markets can be a major determinant of income generated for smallholders. Lack of these markets generally increases the risk of receiving little, or no income at all, for the jatropha seed they have produced. Conversely, the derived income from selling jatropha seeds may increase (and become more stable) as the industry matures and undergoes learning for quality control and skilling up of labourers (Nielsen, 2011).

Opportunity costs (for land, time etc) can be another determinant of income generation potential for jatropha smallholders. Portale (2012) reviewing the smallholder Diligent project in Northern Tanzania found that jatropha production would provide more income to households than growing other cash crops (with the exception of onions which had a slightly higher value).[19] In a similar manner, farmers in parts of Tanzania believed that even

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[18] FACT Foundation pays 5 meticais per kg (USD 0.7 per kg) (personal communication).

[19] This assessment was, however, based on estimated jatropha yields and not actual smallholder experience.

if local food production falls short (due to cropland conversion to jatropha) the increased income from selling jatropha seeds would still allow them to buy sufficient quantities of food from other sources (WWF-TPO, 2009). In both cases the opportunity costs associated with the land allocated to jatropha production, was lower than the income expected from selling jatropha seeds. In this respect it made economic sense to grow jatropha rather than food crops.

On the contrary Grimsby et al, (2012) found that it took almost a full day's labour to pick and prepare jatropha seeds for oil extraction and subsequent use in a multifunctional jatropha platform. This only earned the picker USD 0.90 per day. Smallholders were prepared to allow other villagers pick the seeds from jatropha hedges for free as it was not worth their time to collect the seed. This suggests that oil from jatropha fences could prove to be uneconomical but could also be interpreted that jatropha hedge-groves may become an important safety net for the very poor and landless in such villages. Time taken to pick seeds is directly linked to yield, and if yields are improved, then the per day labour returns will also improve (Borman et al., 2012; Everson et al., 2012).

Smallholder production for uses other than fuel

As mentioned in Section 3.2.1.4 jatropha oil can be used to produce soap. This can have direct or indirect impacts on household or local income generation. Direct household and local income benefits will accrue if the soap-producing households/villages sell their produce in the external market. Conversely, indirect household income benefits will emerge if the soap is used to substitute (or supplement) such acquisitions. In this respect there can be household income savings due to lower purchasing costs, which can result in increases in the household's disposable income.

Studies have suggested that the use of jatropha seeds for local soap production may have significantly better economic returns than selling seeds into the transportation fuel market (Nielsen, 2011; Tigere et al., 2006). In areas where jatropha is grown as hedges, (e.g. in Mozambique) soap production can supplement farmers' income from cash crops (de Jongh and Nielsen, 2011). Even so, significant income returns from such ventures are positive only after seven or eight years of cultivation (Dimpl et al., 2011). Soap-making has also been considered as an income opportunity for women groups. For example, in Ghana, women groups are producing soap for external sale while in Tanzania and Zambia, village women's groups were trained to manage jatropha and establish soap businesses (UNDESA, 2007).

The above suggest that small-scale jatropha projects focusing on soap production could potentially be a better income generation activity than growing and selling jatropha seeds for fuel (Shumba et al., 2011; Schut et al., 2011)

3.4.2 Energy security and access to energy resources

As with rural development, the impact of jatropha production and use on energy security can manifest on different scales (household, local, national). Most large-scale and several smallholder-centred jatropha projects in Africa produce jatropha as a biodiesel feedstock destined for national or international fuel blending (Types 3-4 projects, Figure 1). In such projects few of the fuel benefits are returned to the local communities where jatropha is grown.[20]

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[20] This is despite the fact that these communities typically rely on low quality, traditional biomass fuels for most of their energy needs.

Jatropha biodiesel production globally is very modest when compared to other biofuels such as rapeseed/soybean biodiesel and sugarcane/maize ethanol. A report by Dimpl et al. (2011) reviewed projects around the world that have been using vegetable oil for small-scale electricity generation. The review highlights the difficulty in transforming jatropha from a local, small-scale produce into a major global export commodity. One of the most significant issues highlighted was the unreliability of supply to allow penetration into global export markets for biofuels. The quantity (and quality) of oil seed produced has been too variable to allow for steady power generation and commercial production. Problems relating to quality control and supply flow are therefore the key factors that need to be addressed before jatropha can become a major export item.

In the African context jatropha production is expected to remain relatively modest in the short-to-medium term. As a result jatropha biodiesel's contribution to the national energy security of African countries will be very limited, especially when considering the very modest biodiesel mandates (as compared to ethanol mandates) already put in place in most African countries (REN21, 2012).

The prospect of jatropha biodiesel increasing the national energy security of African countries may be even more limited as most foreign investors generally target the export market with domestic markets being only a secondary target. For oil processing to be competitive against diesel fuel, the price of seeds and labour must be low (Section 3.4.2.2). Low seed prices mean that jatropha smallholders and outgrowers receive a lower price for their product and make poor returns to jatropha oil because existing seed prices are too expensive. This means that jatropha-based biofuels may not be a socially or economically viable solution to national energy security in parts of Africa. However, the exceptionally high costs of diesel in land-locked countries such as Zambia, particularly in areas away from large cities, may make jatropha production more economically competitive. In any case even in such contexts sufficiently high yields must be attained in order to boost jatropha fuel economic viability and give an opportunity to contribute positively to national energy security (Borman et al., 2012).

Jatropha-based biofuels can, on the other hand, contribute much more substantially to local and household energy security. Small-scale biofuel schemes (Type 1 projects, Figure 1) are particularly beneficial when alternative local energy carriers are costlier (e.g., in remote areas with high fuel transportation costs) or are associated with other high indirect costs. Such projects can entail the use of straight jatropha oil for electricity generation (e.g. the Folkercentre project in Mali) or in multi-platform centers such as those planned in Tanzania which link power generators, mills and water pumps (TaTEDO, 2008; Nygaard, 2010). There is extensive evidence that access to modern energy, even if only in small amounts, can have substantive developmental benefits (World Bank, 2011).

Section 3.4.1.1 mentioned the successful cases of rural electrification projects such as MFC Mali Garalo and KAKUTE in Tanzania. TaTEDO (also in Tanzania) engages smallholder farmers at a village scale to produce biofuel for transport, and has set up similar rural electrification and cost-recovery systems to MFC project in Mali, using straight vegetable oil to generate electricity for sale to households (GTZ, 2005; TaTEDO, 2008). However it should be kept in mind that in such projects jatropha oil would only result in relatively low amounts of electricity per household that can be sufficient for lighting and low watt applications, but insufficient for cooking and space heating (Wijgerse, 2008).

However, not all jatropha-based rural electrification projects are successful. ADPP-FACT reports a plan for 25 rural communities to produce 250 ha of jatropha, but as of 2011 no vegetable oil-based electricity had been generated (Dimpl et al., 2011). GTZ's project, "Sustainable Biomass Electrification", aimed to provide electricity to 3,000 people but a complete biofuel value chain was not developed as of 2011 (further to which the production of jatropha-generated electricity was considered economically unviable) (Dimpl et al., 2011).The above suggest that the optimism for jatropha as a rural energy solution needs to be tempered by the fact that even those partly successful examples in Mali and Tanzania have difficulty creating an economically viable jatropha energy system. As mentioned in the beginning of this section it is the supply of jatropha seeds and the quality of the raw oil that are key limiting factors not only in the success of small-scale industry, but in the industry as a whole (Dimpl et al., 2011).

Other options to jatropha-based rural electrification schemes include the direct use of jatropha oil for lighting. The viscous jatropha oil does not wick well, and specially designed lamps are needed to burn it. However, these lamps are reported to burn longer than normal paraffin lamps on a similar volume of fuel (Boerstler, 2010). Jatropha oil stoves have also been proposed but are not very efficient or suffer from technical and cost considerations (Boerstler, 2010). Currently no example has been found where such stoves are being actively promoted. Finally, the use of jatropha seedcake as a fuel briquette has some potential with evidence suggesting that it was more efficient than fuelwood when used in a traditional three stone stove (Boerstler, 2010). Jatropha seedcake can also be used in methane digesters and hence provide methane fuel in addition to the jatropha oil fuel (Singh et al., 2008).

3.4.3 Food security and access to food

As discussed in Section 3.2.1.2 jatropha production can compete indirectly with food production. As a result jatropha production can potentially affect food security at the household/local and the national level. The impact on food security can be negative (e.g. through diversion of land, labour, fertilizers and water from food to jatropha production) or positive (through higher incomes to jatropha producing households and/or overall stimulation of the agricultural sector).

Large-scale Jatropha production schemes (Type 2 and 4 projects, Figure 1) involve the extensive cultivation of jatropha along large tracks of land. This usually entails large-scale land use changes, sometimes involving the conversion of idle agricultural land, or even land under other agricultural uses (Section 3.1). Outgrower schemes can also be linked to such large-scale jatropha projects. Switching from food to jatropha production can pose a threat to local food production, and as such threaten food security at the household and the local level. For example, large-scale projects such as the SUN Biofuels project in Mozambique have been accused of displacing subsistence agricultural activities (Kitabu, 2011). From the literature it is not clear if these displaced community members had subsequent access to other agricultural land, but if not this could result in these displaced families having lower levels of food security. Similar impacts on household/local food security can also be expected when smallholder farmers (Type 3 project, Figure 1) switch from producing food crops to jatropha.

Section 3.4.1.2 has discussed how jatropha production can in some cases result directly and indirectly into higher household incomes. Higher incomes can increase the food security of households even if there has been a switch from food production to jatropha production. Furthermore, diversion of labour to jatropha production can sometimes stimulate local food production through the development of local food markets and the empowerment of smallholders to invest in agricultural inputs such as fertilizer, hence enhancing food production through intensification (Cotula et al., 2008). For example, some plantations have made tractors available to smallholders to assist them in their local agricultural activities, whilst in other projects women labourers were allowed to leave early in order to tend their smallholder fields (von Maltitz et al., 2012).

Jatropha-related, regional and national level impacts on food security are less easy to delineate. One of the reasons is that such studies are based on modeling exercises which sometimes adopt optimistic assumptions about jatropha yields.

FAO's Bioenergy and Food Security (BEFS) project suggests that food production would increase slightly under most biofuel investment scenarios (Maltsoglou and Khwaja, 2010). It was found that increased feedstock production would most likely adversely affect other cash crops that are traded internationally. In the final conclusion, it was stated that *"while all biofuel production scenarios improve household welfare, it is the small- scale outgrower schemes, especially for typical smallholder crops such as cassava and jatropha which are most effective at raising poorer households incomes"* (Maltsoglou and Khwaja, 2010: 5).

On the other hand, Arndt et al. (2011) have shown that significant food-fuel tradeoffs are to be expected if women are more actively involved in feedstock production in Mozambique. Increasing women's participation is not expected to affect overall economic growth in the country (also see Arndt et al., 2010) but it is expected to curb the effects of biofuel production on poverty alleviation as a result of higher food prices (Arndt et al., 2011).

There have been some suggestions on how to reduce potential competition between food and jatropha production. The main proposal has been to locate jatropha production in marginal lands. However as it was discussed this has not been the case so far, not the least because the expected yields will be too low to allow the economic viability of such jatropha projects (Section 3.1).

Intercropping can also be practiced, with jatropha plants grown at wider intervals to allow the production of other cash crops or with grass to allow grazing. Field experiments on allycropping systems show that this greatly reduces jatropha yields and growth rates during the early years of establishment (Everson et al., 2012). The opportunity to intercrop ends after five years when the canopy closes. Another strategy is to grow the jatropha plants as a live fence but this raises the cost of collection (Section 3.4.1.2).

Perhaps the only reasonable option to minimize this competition would be to increase land intensification for food production. Historically, increases in agricultural production in Africa have been achieved through the expansion of agricultural land rather than through the intensification of existing agricultural activities. For most African countries it is not land availability, but rather a constraint in farming practices, and in particular fertilizer use, that can result in food insecurity. Increasing farming efficiency could, in theory, allow for both food and fuel production without requiring extensive areas of new land being brought under agriculture. However the environmental burdens associated with such intensification should not be discounted.

3.4.4 Health

The toxicity of jatropha's seeds, oil and other co-products (e.g., seedcake) can be potentially threatening to human health and caution has been suggested during the production and use of such products particularly in enclosed spaces (Achten et al., 2008). There have also been fears that children may accidently eat jatropha seeds and that this could prove fatal (Achten et al., 2007). Overexposure to jatropha is also believed to be damaging to the skin, eyes and upper respiratory system, and it could possibly contribute to the development of certain types of cancer (Gressel, 2007; Horiuchi et al., 1987; Hirota et al., 1988). Epidemiological studies on mice have shown that components of jatropha oil, including phorbol ester, can promote tumor growth (Goel et al., 2007).

On the other hand the combustion of jatropha-based fuel might provide positive health benefits at the household level through the decrease of indoor air pollution. Smoke and other pollutants from the combustion of traditional biomass fuels (e.g. charcoal, wood, dung)[21] has been found to be a potent health hazard to rural and urban dwellers in Africa. The health benefits of substituting traditional biomass fuels would depend on the type of jatropha-based fuel. In any case, the large-scale displacement of traditional cooking fuels with jatropha based fuels presently seems unlikely.

3.4.5 Land tenure and social conflicts

There are several cases in which the access of poor people to land has been compromised due to biofuel expansion. Examples include the displacement of poor families in Mozambique/Tanzania, concentration of land to powerful actors in Brazil/Indonesia/Papua New Guinea, loss of land rights through coercion and lack of information in Indonesia or even aggressive land seizures in Colombia (Cotula et al., 2008). Such phenomena can be very difficult to be resolved due to asymmetrical power between actors within biofuel chains (Lehtonen, 2012).

In Africa land tenure is complex and the details of the legislation vary between countries. Furthermore, even within countries land tenure regimes may vary according to traditions or due to power-sharing arrangements linked to local formal and informal institutional structures. Nevertheless, in almost all countries large portions of the rural areas are in some form of customary tenure, with communal use of the rangelands and forests. These areas play an important role for the well-being of local communities as they are commonly used for livestock grazing and the collection of a wide range of woodland products that form a substantive contribution to household livelihoods, particularly for poor and marginalized groups within the community (Shackleton and Gumbo, 2010; Shackleton et al., 2010).

In legislation, such land is often recognized as “communal land” with no private ownership. The level of influence that a community as a whole has on approving biofuel projects in its land varies between locations. In many African countries community land managed, and used by the local community (termed “village land” in Tanzania), is converted to state land (termed “general land” in Tanzania) during the process of setting up lease agreements with investors (Borras and Franco, 2012). This is a formal process where tenure is permanently transferred to the state, who then leases the land to investors. Though legislation differs between countries, lease fees would typically go to the state, with the community members only benefiting from job opportunities. If an investment project fails then the land typically remains state land rather than reverting back to the community (Borras and Franco, 2012). The situation therefore can potentially arise that a community loses both their traditional access to land as well as the benefits they had expected to obtain from the biofuel projects.[22]

There have been allegations that communities in Tanzania, Mozambique, Ghana, Kenya and Zambia lost access to their communal land after large-scale jatropha production was initiated (FoE, 2011; Makutsa, 2010). Agoramoorthy et al. (2009) suggest that the

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[21] Charcoal and fuelwood remain the primary energy sources for the poor in most of Africa’s large cities (Bailis et al., 2005; IEA, 2011; Scholes et al., 2011). The fumes from charcoal and wood burning have substantive health impacts and cause an estimated 400,000 deaths annually in Africa (Bailis et al., 2005). .

[22] On some occasions local working populations are at the whims of investors. For example, East African Biodiesel in Tanzania threatened villagers they would relocate their activities to other villages unless the local community granted them the full requested plantation for their jatropha project (Habib-Mintz, 2010).

aggressive jatropha expansion facilitated by the Indian government and the biofuel industry may displace millions of poor rural farmers from areas that they rely for their food, fuel wood, fodder and timber.

Loss of land tenure can be an agent of social conflict within the affected communities and beyond. Ariza-Montobbio and Lele (2010) have shown that conflicts related to jatropha projects (particularly failed jatropha projects) can go beyond loss of land tenure and can manifest across several levels:

- within households over the responsibility over, and the response after, the failure of jatropha cultivation;
- between jatropha-growing communities and outsiders, e.g. companies and NGOs promoting Jatropha;
- between farmers (including promoters) and the private companies, when the companies did not meet their initial promises of assisting the farmers during the production phase and buying the jatropha seeds at remunerative prices.

Finally, it should be mentioned that, as with any other kind of agricultural activity in Africa, there could be gender-related angles to issues of land tenure and conflicts associated with jatropha production. Longstanding gender inequality in many parts of Africa (men generally own the land in Africa) may interfere with efforts to leverage jatropha markets and improve women's livelihoods and income. For example, in Tanzania, women who are responsible for agricultural labour do not own the land and therefore do not gain benefits from planting jatropha (van Eijck, 2007). In Mali there have been disputes between jatropha hedge owners and women groups who wanted to harvest jatropha seeds. As soon as the men discovered there was financial benefit to be made out of jatropha they demanded a share of profit, thus deterring women groups from being involved in such small-scale jatropha projects (Henning, 2009). In this respect Rossi and Lambrou (2008) suggest that some of the potential risks from (and benefits of) first-generation biofuel expansion (including jatropha) in Sub-Saharan Africa can be gender-differentiated with women being more likely to face the negative socioeconomic and environmental dimensions of biofuel expansion.

4. Sugarcane ethanol

4.1 Background

Large parts of Africa are suitable for sugarcane cultivation. Nevertheless, sugar production in Africa is still modest when compared to Brazil and India. Sugarcane production in Africa currently accounts for 5.4 per cent of global production (Table 5). However, African countries exhibit some of the highest sugarcane yields in the world and are home to very efficient sugar industries. For example, Malawi, Tanzania and Zambia consistently report national average sugarcane yields of over 100 tons/ha (Table 5). As a result trading blocks such as the South Africa Development Community (SADC) are net-sugar exporters.[23]

Table 5: Top-15 sugarcane producers in Africa (2010)

	Area (1000 ha)	Production (1000 t)	% of global production	Yield (t/ha)
South Africa	267	16,016	0.95	60.0
Sudan (former)	67	7,527	0.45	112.0
Kenya	69	5,710	0.34	83.1
Swaziland	52	5,000	0.30	96.2
Mauritius	59	4,366	0.26	74.4
Zambia	39	4,050	0.24	105.2
Zimbabwe	39	3,100	0.18	79.5
Madagascar	95	3,000	0.18	31.6
Mozambique	215	2,800	0.17	13.0
Tanzania	23	2,750	0.16	119.6
Malawi	23	2,500	0.15	108.7
Ethiopia	19	2,400	0.14	126.9
Uganda	40	2,400	0.14	60.0
DRC Congo	40	1,827	0.11	45.7
Côte d'Ivoire	22	1,650	0.10	75.0
Middle Africa	232	5,012	0.30	21.6
Western Africa	157	5,764	0.34	36.6
Southern Africa	319	21,016	1.25	65.9
Northern Africa	212	23,868	1.42	112.6
Eastern Africa	657	35,415	2.10	53.9
Africa, Total	**1,577**	**91,075**	**5.40**	**57.8**
India	4,200	277,750	16.48	66.1
Brazil	9,081	719,157	42.67	79.2
World	**23,815**	**1,685,445**		**70.8**

Source (FAO, 2010)

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[23] Access to preferential sugar markets in the EU and the US also contribute to the export-oriented nature of sugar production in the region (Batidzirai and Johnson, 2012).

Sugarcane ethanol production also has a relatively long history in several parts of the continent. Despite attempts to initiate sugarcane ethanol blending in the past (Section 1.2), most of the ethanol produced in the region is used for industrial and potable purposes or is exported. Nevertheless, some countries such as Malawi have been continuously blending fuel ethanol with petrol (generally E10-15) since the inception of its programme in 1982 (Batidzirai and Johnson, 2012). Table 6 shows the existing and planned bioethanol production capacity in some countries of southern Africa.

Table 6: Current and planned fuel ethanol production capacity in four African countries

	Status	**Distillery capacity (ML/yr)**
Malawi	Existing	30
South Africa	Planned (maize-based)	155
Zambia	Planned	37
Zimbabwe	Existing	40

Source: Adapted from (Batidzirai and Johnson, 2012)

However, southern Africa has a great potential to produce bioenergy from sugarcane using available, unutilized, and suitable land without compromising food production or degrading ecosystems.

Watson (2011) calculates that at least 6 million ha of land is readily available and suitable for rain-fed sugarcane agriculture across six southern African countries (Table 7). To put this figure into perspective, in 2010 Brazil used about 9 million ha for sugar and ethanol production (UNICA, 2012). Allowing for the relatively higher sugarcane yields in parts of southern Africa (Table 5) it can be inferred that the raw sugarcane potential in southern Africa is comparable to that of Brazil (Batidzirai and Johnson, 2012). The above imply that there is a huge untapped potential to produce sugarcane ethanol in the region and that land is unlikely to be the limiting factor for sugarcane expansion. However the actual implementation of sugarcane ethanol production in Africa might affect natural habitats and compete with food production as discussed below, refer to Sections 4.3 and 4.4.3.

Table 7: Land availability for rain-fed sugarcane agriculture in six African countries

	Angola	**Malawi**	**Mozambique**	**Tanzania**	**Zambia**	**Zimbabwe**
Total land area, of which	124670	9408	78409	87869	74339	38667
Protected areas	1395	595	4602	1223	2433	1860
Slopes >16%	1389	580	4530	1217	2427	1855
Available and suitable	1127	206	2338	467	1178	620
% of country available and suitable for sugarcane	0.90	2.19	2.98	0.53	1.58	1.60
% of arable land available and suitable	37.7	8.7	80.1	1.3	22.3	22.9

Source: Adapted from (Watson, 2011)

4.2 Ecosystem services

4.2.1 Provisioning services

4.2.1.1 Fuel

Several LCAs have shown that sugarcane and molasses ethanol exhibit some of the highest EROIs compared to other biofuel practices around the world (Stromberg and Gasparatos, 2012). EROIs of sugarcane ethanol can in several cases be higher than 8.0 (Table 8). Currently there are few complete LCAs for sugarcane ethanol in the African contexts. Based on yield assumptions and current technologies, sugarcane ethanol in southern Africa can reach EROIs of approximately 8.0 (Table 8).

Table 8: Energy yields and EROIs for sugarcane ethanol

Feedstock	Country	Energy yield (GJ/Kg feedstock)	Energy yield (GJ/ha feedstock)	EROI (GJout/ GJin)	Source
Sugarcane	**Brazil**	1.9	132.0	8.5	(Smeets et al., 2008; Macedo et al., 2004)
	Brazil	1.9	127.0	3.1	(Smeets et al., 2008; Oliveira et al., 2005)
	Brazil	2.0	159.0	3.9	(Smeets et al., 2008; Oliveira et al., 2005)
	Brazil	1.8	140.0	9.3	(Boddey et al.,2008)
	Brazil	1.6	130.0	8.2	(Pereira and Ortega, 2010)
	Brazil	1.8	130.0	NA [a]	(de Vries et al., 2010)
	Colombia	1.6	185.0	NA [a]	(Quintero et al., 2008)
	Mexico	1.8	123.01	4.7	(Garcia et al., 2011)
	Southern Africa	1.2	960.0	8.0	(von Maltitz and Brent, 2008)
Molasses	**Thailand**	1.9	132.0	0.8	(Nguyen, et al., 2007)
	Thailand	4.6	NA [a]	0.8	(Silalertruska and Gheewala, 2009)
	Nepal	4.9	960.0	0.6	(Khatiwada and Silveira, 2009)

Source: Adapted from (Stromberg and Gasparatos, 2012)
Notes
[a] The information was not readily reported or could not be derived using the information reported in the respective study

These high EROIs can be achieved by a combination of high yielding varieties, improved agricultural practices and other technical means. A commonly used strategy that boosts the energy provision of sugarcane ethanol is the cogeneration of electricity from bagasse burning in sugarcane mills.[24] As a by-product of sugar and ethanol production, bagasse can be burned in high-pressure boilers to provide electricity, which is primarily used in sugar mills or sold in the national electricity grid (Pellegrini and de Oliveira, 2011).

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[24] Bagasse is what remains from the sugarcane stalk following crushing for the extraction of sugarcane juice.

Due to such factors LCA meta-analyses have shown that sugarcane ethanol offers the highest energy gains (de Vries et al., 2010) and very high fossil energy improvements; sometimes well over 90 per cent (Menichetti and Otto, 2009) than any other first-generation biofuel practice. As a result sugarcane ethanol can potentially increase energy security in Africa, particularly in the regional and the national level, as has been the case in Brazil (Section 4.4.2).

4.2.1.2 Food, fodder and fibre

In contrast to jatropha, sugarcane is a crop used extensively in the food industry. As a result there is potential not only for indirect competition with other provisioning services such as food, fodder and fibre for land, labour and water (as is the case with jatropha, Section 3.2.1.2) but also potential for direct competition (i.e., direct displacement of sugarcane from food purposes, to fuel production).

Studies from Sao Paulo State (the centre of Brazilian sugarcane ethanol production) have shown that low-productivity pastureland and, to a lesser extent, peanut and rice cultivation was lost due to sugarcane expansion (Goncalves et al., 2007). Since 2006, approximately 90 per cent of new sugarcane area was located on former pastureland, which might have contributed to the reduction of milk farming in the state (Novo et al., 2010). Other crops affected included tomatoes and oranges in Sao Paulo and coffee in Sao Paulo, Espırito Santo, and Minas Gerais (Smeets et al., 2008). On the other hand bean, corn, poultry, and egg production does not seem to have been affected by sugarcane expansion in the State of Sao Paulo.

The above suggest a rather limited indirect competition between sugarcane production (for ethanol) and food production in Brazil. This has been possible due to a combination of factors. First of all the prevailing sugarcane ethanol production model is highly efficient in terms of land and other agricultural inputs is relies almost exclusively on sugarcane produced in large plantations which are integrated with (or are in proximity to) sugar mills and distilleries. This production mode is highly efficient as it achieves high sugar and ethanol yields per hectare. In fact sugarcane ethanol can achieve the highest energy production per hectare of allocated land than any other first-generation feedstock (e.g. Stromberg and Gasparatos, 2012). Secondly as most of the agricultural land in Sao Paulo State lost to sugarcane was low intensity pastureland, it forced productivity increases in the livestock sector that compensated for this lost land.

Competition between sugarcane production (for ethanol) and food production has been less well studied in Africa. There have been allegations that large-scale ethanol project might displace food production, e.g. rice agriculture (ABN, 2007). This suggests that it is likely that sugarcane (for ethanol) can compete, directly and indirectly, with food production in parts of the continent. Considering the structure of the agricultural sector and the chronic food insecurity issues in parts of Africa, sugarcane ethanol expansion might have much more important food security implications in Africa than in Brazil (Section 4.4.3).

4.2.1.3 Water

Sugarcane ethanol production can affect freshwater ecosystem services either through their overexploitation or their degradation.

Feedstock production (agricultural phase) has by far the highest impact on freshwater ecosystem services associated with sugarcane ethanol (Gerbens-Leenes et al., 2012). However, in most parts of the world, sugarcane cultivation is predominantly rain-fed, exhibiting some of the lowest water requirements when compared to other biofuel practices (Table 9).

Table 9: Water footprint (WF) of different biofuel practices (expressed as L water per L of biofuel)

	Blue WF	Green WF	Total WF
Ethanol			
Sugar beet	822	566	1388
Sugarcane	1364	1152	2516
Maize	1013	1557	2570
Cassava	420	2506	2926
Wheat	2873	2073	4946
Sweet sorghum	4254	5558	9812
Biodiesel			
Soybean	7521	6155	13676
Rapeseed	8487	5714	14201
Jatropha [a]	11636	8288	19924

[a] Average for 5 countries (India, Indonesia, Nicaragua, Brazil and Guatemala). The water requirement of jatropha reported in this study has been contested (e.g. Jongschaap et al., 2009; Maes et al., 2009b).
Source: Adapted from (Gerbens-Leenes et al., 2009)

Hydrological studies of the SEKAB large-scale sugarcane project in the Rufiji delta (Tanzania) suggest that the project would have used 160 million m^3 of water per year for the irrigation of 15,000 ha of sugarcane (Franke et al, 2010). Since the project was located towards the end of the catchment area, it would have had relatively limited impact on downstream users, but would have reduced stream-flow by up to 40 per cent during drought years and by 10–20 per cent during normal years (Franke et al, 2010)

To the authors best knowledge there are no studies that explore how sugarcane cultivation affects water quality in Africa. However there is significant evidence from other areas of the world, particularly in Brazil. Sugarcane cultivation is blamed for polluting water bodies across Sao Paulo State largely due its fertilizer-intensive nature (FAO, 2004; Martinelli and Filoso, 2008) and the use of dangerous agrochemicals (Lara et al., 2001; Lehtonen, 2010). High nitrogen loading, acidification, increased turbidity and oxygen imbalance have been reported in catchment areas that contain sugarcane plantations (Gunkel et al., 2007; Filoso et al., 2003). Sugarcane burning has also been linked to the acidification of streams and the detection of PAHs in lake sediments (Martinelli and Filoso, 2008). Finally, banned agrochemicals linked to sugarcane agriculture have been identified in sediments and fish

(Martinelli and Filoso, 2008) while several cases of agrochemical misuse have resulted in water and soil contamination (Lehtonen, 2010), posing a significant risk to public health (Section 4.4.4).

4.2.2 Regulating services

4.2.2.1 Climate change regulation

Several LCAs have claimed that Brazilian sugarcane ethanol exhibits higher GHG savings than any other first-generation biofuel practice (Menichetti and Otto, 2009; Zah et al., 2007; de Vries et al., 2010). In several cases these GHG savings can be well above 80 per cent (Menichetti and Otto, 2009; Zah et al., 2007; de Vries et al., 2010). However, if emissions from direct and indirect LUCC effects are factored into such LCAs, then Brazilian bioethanol might incur carbon debts. For example, sugarcane ethanol production in the Cerrado woodland can create carbon debt that would take 17 years to repay (Fargione et al., 2008). Other studies suggest payback times of 3–10 years for sugarcane ethanol production in agricultural lands and 15–39 years from previously forested lands (RFA, 2008). All these carbon debts are considered to be moderate compared to those associated with feedstocks such as palm oil and soybean oil (Fargione et al., 2008; Gibbs et al., 2008). Indirect LUCC[25] effects due to sugarcane expansion in south Brazil might also create a carbon debt of up to 44 years by 2020 (Lapola et al., 2010). Conversely, a large-scale modeling exercise using the Brazilian Land Use Model (BLUM) predicted little future deforestation from sugarcane expansion in the southeast Brazil (Nassar at al., 2009). Due to these relatively low anticipated carbon debts and high GHG savings, consistently over 50 per cent including emissions from direct and indirect LUCC effects, the US Environmental Protection Agency (EPA) has designated Brazilian bioethanol an "advanced biofuel" (EPA, 2009).

4.2.2.2 Air quality regulation

Goldemberg (2008) has partially credited air quality improvements in Sao Paulo metropolitan area to sugarcane ethanol use. The rapid introduction of flex fuel vehicles (FFVs) since 2003 accelerated the gradual de-phasing of older, more polluting and less energy efficient vehicles and might have had a ripple effect on urban air quality (Gasparatos et al., 2012a). Yet, there is limited empirical evidence regarding the links between bioethanol use and ambient air quality improvements in Brazil, particularly in urban settings. There are some indications that bioethanol, as a driver of vehicle fleet modernization, might have resulted in lower air pollutant emission from the transport sector. This is mainly due to the fact that vehicles running on ethanol or ethanol/gasoline blends exhibit decreasing emission factors, particularly for carbon monoxide (CO) and nitrogen oxides (NOx), since the early 1980s (CETESB, 2012). In addition the emission factors of these vehicles are much lower than the emission factors of cars running on pure gasoline during the same period (CETESB, 2012). Finally, ethanol fuel does not contain any sulfur, which suggests that the widespread adoption of ethanol fuel in the transport sector prevented significant sulphur dioxide emissions (SO_2) in the atmosphere.

However recent studies have shown that for several pollutants the life-cycle emissions of sugarcane ethanol are higher than those of conventional transport fuel (Tsao et al., 2012). For these pollutants the life-cycle emissions are usually dominated by the agricultural phase of sugarcane ethanol's life cycle and agricultural burning in particular (Tsao et al., 2012).

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[25] Replacing rangeland with sugarcane in the south of the country might push the rangeland frontier into the Amazon and cause significant deforestation and GHG emissions.

Such pollutants include particulate matter with aerodynamic diameters of <2.5 μm (PM2.5) and <10 μm (PM10) (Cancado et al., 2006; Castanho and Artaxo, 2001; Lara et al., 2005; Martinelli et al., 2002), polycyclic aromatic hydrocarbons (PAHs) (Martinelli and Filoso, 2008) and NOx (Oppenheimer et al., 2004). The emission of pollutants linked to agricultural burning has been shown to have important health effects (Section 4.4.4).

To the authors best knowledge there have not been any LCA studies quantifying the emission of atmospheric pollutants from sugarcane ethanol production and combustion in Africa. There are some suggestions that sugarcane ethanol-influenced transport fleet renewal can potentially have a positive impact on urban air quality in cities in developing countries, including Sub-Saharan Africa (Kojima and Johnson, 2005). However this has yet to be proved or modeled. On the other hand lower emissions from ethanol stoves have been studied and have been linked to public health benefits due to reduced indoor air pollution (Section 4.4.4).

4.2.2.3 Erosion regulation

Sugarcane landscapes have been shown to cause significant soil erosion. Soil erosion tends to be much higher in sugarcane landscapes compared to adjacent pasture and forested areas. This is because extensive areas of bare soil are left exposed to intense rain and winds, during the initial land conversion (removal of native vegetation) and the period between crop harvest and regrowth (Martinelli and Filoso, 2008). Studies in Brazil have estimated a soil erosion potential rate of 5.2 times higher than that of soil formation (de Oliveira et al., 2005). A rank of the most common biofuel feedstocks in order of decreasing soil erosion is: cassava, soybean, sugarcane, sorghum, corn, sugar beet, winter wheat, oil palm and winter rapeseed (de Vries et al., 2010).

4.2.3 Cultural services

As is the case with jatropha landscapes (Section 3.2.3), very little research has been performed to assess potential impacts of sugarcane landscapes on cultural ecosystem services in Africa and beyond.

Potential displacement of traditional crops or the direct/indirect loss of highly biodiverse undisturbed ecosystems that can attract tourism activities might contribute to the loss of cutural services. Significant research is needed to understand the mechanisms and the magnitude of cutural impacts.

4.3 Biodiversity

Extensive sugarcane monocultures are known to support a relatively limited number of species (Oliver, 2005). Only a few weed and terrestrial animal species (e.g. rats, snakes, spiders and ants) are encountered in sugarcane plantations (von Maltitz et al., 2010). Bird diversity in cane plantations is also particularly low (Petit et al., 1999; Martin and Catterall, 2001).

Water pollution from sugarcane plantations and mills (Section 4.2.1.3) can also contribute to biodiversity loss in riparian ecosystems located in the vicinity of sugarcane plantations.

However, it is direct and indirect LUCC effects of sugarcane expansion that can be a much more significant driver of biodiversity loss. For example, according to the Brazilian Forest Code farming establishments in Brazil should set-aside a portion of forested area within their borders. In the Southeast, where most of sugar/ethanol production is located, this set-aside forested area should be at least 20 per cent of the establishment's land.[26] However, there are strong indications that most sugarcane producers do not comply with this obligation. It has been suggested that failure to comply with this policy, and particularly with the preservation of riparian ecosystems can decrease biodiversity in the State of Sao Paulo (Martinelli and Filoso, 2008). An estimated 75 per cent of riparian buffer zones have already been converted to sugarcane and pasture which has increased generalist species such as the capybara *Hyfrochoerus hydrochaeris* (Koh et al., 2009). It is feared that the degradation of such highly biodiverse riparian ecosystems can further reduce water quality, which, in turn, will further threaten biodiversity in the region (Martinelli and Filoso, 2008).

LUCC effects due to the future expansion of sugarcane cultivation can pose an even greater threat to biodiversity within Brazil. Even though sugarcane grows poorly in humid rainforests and it is legally prohibited to expand sugarcane production in sensitive ecological areas such as the Amazon, the Pantanal and the Cerrado, some models predict that sugarcane expansion in the Brazilian Southeast might trigger indirect LUCC effects and push the agricultural frontier in the Cerrado (Lapola et al., 2010; Smeets et al., 2008; Sparovek et al., 2007) and the Amazon (Lapola et al., 2010). This might potentially lead to biodiversity loss in these two highly biodiverse biomes.

LUCC effects due to sugarcane expansion in Africa might pose similar threats to biodiversity. Currently, to our best knowledge, the only sugarcane ethanol-related investment confirmed and operational in the Ecoenergy project in Bagamoyo, which is located at an abandoned state cattle farm (EcoEnergy, 2012).

However a number of other proposed sugarcane projects in Africa might entail a relatively large-scale clearing of indigenous vegetation. For example, the SEKAB project villages had allocated up to 72 per cent of their communal land to sugarcane production. It is expected that extensive areas of natural vegetation would have been converted to sugarcane potentially having a negative impact on biodiversity. However it is important to consider that substantial degradation of biodiversity might already had been taking place in the absence of biofuel expansion in the area (Arvidson et al., 2009). The main reason is that the livelihood of SEKAB communities in the Rufiji valley highly depends on resources obtained from local ecosystems (up to 85 per cent).

In such contexts, apart from **direct** biodiversity impacts due to LUCC effects, sugarcane expansion can **indirectly** affect biodiversity through overexploitation. If natural vegetation is converted to sugarcane, then there might be a high degree of resource harvesting in the remaining forests, potentially leading to the overexploitation of commercially valuable species and eventual biodiversity decline (Sulle and Nelson, 2009).

In order to avoid the loss of important biodiversity due to LUCC effects, the High Conservation Value (HCV) methodology was applied to ensure that important biodiversity was protected in the vicinity of the SEKAB project villages. In fact biodiversity may have been better conserved within the SEKAB plantation and its "no-go" zones than if no project was in place (Arvidson et al., 2009).

In order to ensure the effective preservation of valuable biodiversity in such contexts, then alternative livelihood mechanisms must be created. These mechanisms should be able to reduce human pressure on ecosystems and avoid the potential overexploitation of valuable species (Arvidson et al., 2009).

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[26] The Brazilian Forest code was amended in April 2012. The new version has gathered criticisms by environmentalist as being inadequate to halt deforestation within the country (Tollefson, 2012).

The above suggest that biodiversity conservation and poverty alleviation is a particularly tough puzzle to solve. Understanding biodiversity and human livelihood trade-offs is important for minimizing adverse biodiversity impacts from sugarcane expansion in African.

Finally, unlike jatropha (Section 3.4.4), there is a real potential to reduce deforestation through the use of ethanol gel as a fuel for cooking. As already mentioned (Section 3.4.4) fuelwood and charcoal are the main cooking fuels across Africa and are significant sources of deforestation. Urban charcoal demand has been identified as the main driver of the wide-scale expansion of the rural charcoal sector (Scholes et al., 2011). Switching from such environmentally destructive fuel into ethanol could potentially decrease deforestation and have significant biodiversity benefits. An estimated 60,000–80,000 ha of sugarcane would be sufficient for replacing the entire Tanzanian charcoal market, which is responsible for about 400,000 ha of deforestation per year (EcoEnergy, 2012). There are some relevant pilot projects but significant policy intervention would be needed to facilitate a large-scale transition from charcoal to ethanol (Section 7).

4.4 Human well-being

The socioeconomic conditions of sugarcane ethanol production in Brazil are quite different than those encountered in Africa. In Brazil almost all of the sugarcane is produced in large plantations with smallholders having practically disappeared, particularly in Sao Paulo State that is the centre of Brazilian sugar/ethanol production (Abramovay, 2008). As a result significant power differential have emerged between the agro-industrial oligarchies and the plantations workers (Lehtonen, 2010). On the other hand, the situation in African is different due to the large number of smallholders involved in the sugarcane sector and the informal land tenure institutions to name just two factors. This means that caution should be paid when comparing the human-wellbeing impacts of sugarcane ethanol in the two regions.

4.4.1 Rural development

As with jatropha, sugarcane production can be an agent of rural development through employment and income opportunities (Section 3.4.1).

4.4.1.1 Impact on employment

The sugarcane sector is a major employer within Brazil, with an estimated 1 million persons involved in the industry as a whole (Reporter Brasil, 2009). Most of these jobs still remain low-skill (e.g., cane cutting) but the technological innovation in the sector has boosted high-skill job creation in many regions. Increased mechanization is expected to generate 171,000 high-skilled jobs but is also expected that once pre-harvest sugarcane burning practices are entirely banned, it will eliminate 420,000 low-skill jobs by 2014 in Sao Paulo State alone (Gasparatos et al., 2012a). Indeed, low-skilled migrants are expected to disappear in Sao Paulo's plantations within the next decade, signs of which are already visible. In 2008, the sugarcane complex laid off more people than it will be able to recruit for new tasks related to agricultural mechanization (Abramovay, 2008). What is even more troubling is that only a small proportion of the low-skilled cane cutters who will lose their jobs during this transition will be covered by the Brazilian government's planned retraining schemes (Wilkinson and Herrera, 2010).

Despite limited sugarcane ethanol production, some African countries have a well-established sugar industry (Section 4.1). It is likely that many of the trends observed in the sugar sector will also apply and for ethanol production. The sugar industry is one of the oldest industries in East Africa generating considerable benefits to the national economies.[27] Due to its labour-intensive nature (see above), the sugar industry is one of the largest direct employers in the region. The sector employs directly over 50,000 employees and indirectly over 300,000 small-scale farmers and 10 million people in allied businesses (Sserunkuma and Kimera, n.d.). Sugarcane (for sugar) outgrower programs in Tanzania, South Africa and Kenya have provided substantial rural development benefits and in some circumstances resulted in the development of a relatively prosperous smallholder sector (Matango, 2006; Richardson, 2010). In Kenya, the Mumias Sugar Company was formed in 1973 as an outgrower company and now has 66,000 contracted smallholders cultivating approximately 64,000 hectares within a 40 km radius of the sugarcane processing plant (Mumias Sugar Company, 2009).

4.4.1.2 Impact on income

Income from salaried work in the sugarcane sector has increased in absolute terms. Currently, salaries in Sao Paulo's sugarcane plantations are on average higher than salaries paid in other agricultural sectors (Smeets et al., 2008)[28], but in so me cases these salaries are not high enough to allow workers escape poverty (Martinelli and Filoso, 2008). Crucially, these wages do not necessarily come with a decrease in workload or an improvement in working conditions. Cane-cutters are still largely paid by-metre-harvested (Wilkinson and Herrera, 2010). It is estimated that, while in 1969 a worker harvested an average of 3 metric tons of sugarcane per day, currently a harvest of less than 10–12 metric tons a day is deemed inadequate and can put the job security of the cutter at risk (Ramos, 2006). Correcting for inflation, this represents a decrease in the harvester's pay from BRL 2.73 per metric ton in 1969 to BRL 0.86 per metric ton in 2005 (Ramos, 2006). The structure of this payment scheme combined with the loss of purchasing power in 2008 resulted in several cane cutter strikes in the State of Sao Paulo that year (Reporter Brasil, 2009).

Sugarcane outgrower schemes in Tanzania, such as Kilombero and Mtibwa, have also been relatively successful. At Mtibwa, the proportion of outgrowers living under minimum wage decreased almost threefold between 1998 and 2006. The success of these schemes is attributed largely to the effective organization of outgrowers through associations (Matango, 2006). These associations are governed by democratically elected representatives and provide training, reliable access to financial capital, support in the procurement of inputs, and negotiate with company management for fair prices (Matango, 2006).

On the other hand there have been instances in Kenya of farmers not harvesting their sugarcane for several months due to a lack of capacity by the sugar mills, reducing thus profitability to outgrower farmers (Sserunkuma and Kimera, n.d. undated). This situation can arise either by poor management or due to world markets, as sugar is an internationally traded agricultural commodity. In any case the emergence of demand-supply problems can effectively reduce smallholders' income until better contractual arrangements can be obtained for the small producers. Sometimes, women have also been marginalized and excluded from the growers' associations as reported in Swaziland (FAO, 2008). Richardson (2010) when reviewing large-scale sugar production in Malawi, Mozambique and Zambia concludes that despite national and local benefits such as substantial employment, wages are typically low, poor housing is provided, land rights are poorly negotiated, contracting agreements are too informal and there is unbalanced power between workers in small-scale farming schemes.

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[27] In the early 2000's the sugar industry faced significant problems, partly due to low global sugar prices that affected the sector's economic viability (Sserunkuma and Kimera, n.d. undated; IEA 2005). Poor management, high levels of political interference and corruption were identified as the major contributors to the industry's near collapse in Kenya (Wanyande, 2001; Matango, 2006).

[28] The same trend is observed when comparing the ethanol industry to other industries (e.g., sugar, food, and beverages) in Sao Paulo State (Smeets et al., 2008).

4.4.2 Energy security and access to energy resources

Brazil is the only country in the world where biofuel use has significantly boosted national energy security. In 2009 approximately 11.1 per cent of total final energy consumption was met one way or another from sugarcane ethanol or its co-products (MME, 2011). The high penetration of ethanol in the national energy mix has been a result of the E18–25 blending mandate (REN21, 2012). The Brazilian blending mandate is by far the highest in the world and combined with the popularity of the flex fuel vehicle has resulted in bioethanol constituting 20.4 per cent of the total energy consumed in the transport sector in 2009 (MME, 2011). A consequence of sugarcane ethanol expansion for transport purposes has been the increased cogeneration of electricity from bagasse burning. In 2010, bagasse burning was responsible for the generation of 6.3 GW of electricity, of which the sugar mills used 75 per cent with the rest sold to the national grid (Pellegrini and de Oliveira, 2011).

In Africa sugarcane ethanol has yet to make a significant impact on national energy security with the exception of Mauritius where approximately 22 per cent of the national electricity supply comes from bagasse burning (MEPU, 2010) and in Malawi where there is a 10–20 per cent ethanol blend in petroleum.

Due to the high sugar productivity in some countries of southern Africa (Table 5) and the high costs of transport fuel, particularly in landlocked countries such as Zambia, it might be possible to meet existing blending mandates from relatively limited land. In the case of Zambia the land requirement to meet an E5 mandate might be as low as 3,000 ha (based on Haywood et al., 2008).

Electricity generation from bagasse burning might also produce significant amounts of electricity further boosting national energy security in countries of southern Africa (Batidzirai and Johnson, 2012). It has been estimated that depending on conversion technology the potential for electricity generation in the region from bagasse burning can be as high as 600 GWh (Table 10). This suggests an excellent potential to expand bagasse cogeneration plants, particularly in South Africa, Mauritius, Swaziland, and Zimbabwe. Currently, most sugar mills produce electricity for meeting their own needs and do it rather inefficiently. Realizing this huge electricity cogeneration potential would require substantial investments to upgrade the cogeneration plants and the development of appropriate infrastructure and policy measures to facilitate the export of surplus electricity from sugar mills (Batidzirai and Johnson, 2012).

Table 10: Electricity export potential from bagasse co-generation in southern Africa countries

Country	Cane crushed (1,000 t/yr)	Bagasse [a] (1,000 t/yr)	Power generation 20 bars, 325 C (GWh)	Power generation 45 bars, 440 C (GWh)	Power generation 82 bars, 525 C (GWh)
Angola	360	108	9.0	27.0	46.8
DR Congo	1,669	536	41.7	125.2	217.0
Malawi	1,796	630	44.9	134.7	233.5
Mauritius	5,800	1,560	145.0	435.0	754.0
Mozambique	397	120	9.9	29.8	51.6
South Africa	22,103	6,126	552.6	1,657.7	2,873.4
Swaziland	4,103	1,350	102.6	307.7	533.4
Tanzania	1,289	600	32.2	96.7	167.6
Zambia	1,600	540	40.0	120.0	208.0
Zimbabwe	4,535	1,360	113.4	340.1	589.6

Note: [a] at 50% moisture content
Source: Adapted from (Seebaluck et al., 2008; Batidzirai and Johnson, 2012).

The above suggest that sugarcane ethanol has the potential to increase national and regional energy security, particularly in landlocked countries where fuel imports can be particularly costly. However significant investment in infrastructure and policy development will be required before that is feasible (Section 7).

4.4.3 Food security and access to food

As discussed in Section 4.2.1.2 sugarcane ethanol can compete directly and indirectly with food production. This can impact food security at the household/local, national and international level.

There are no indications to suggest that the direct and indirect competition of sugarcane ethanol production with food production has threatened national food security in Brazil as the existing agricultural land lost to sugarcane was relatively limited (Gasparatos et al., 2012a) (Section 4.2.1.2). In fact, sugarcane ethanol might have had an indirect positive effect on household/local food security due to the higher incomes offered to those working in the sugarcane sector (Section 4.4.1), (Smeets et al., 2008). On the other hand, there are some more substantial concerns that sugarcane bioethanol expansion in Brazil might affect international sugar prices (Koizumi, 2009; Koizumi and Ohga, 2009; Mitchell, 2005). It seems that one of the reasons that sugarcane production has not affected local or national food security has been the prevailing production system that relies almost exclusively on sugarcane produced in large plantations which are integrated with (or are in proximity to) sugar mills and distilleries.

However the situation in Africa is more different with a large number of smallholder and subsistence agriculture still taking place in the areas that have been identified as promising for sugarcane production. As it is the case with jatropha (Section 3.4.3), switching from subsistence agriculture to sugarcane agriculture (for ethanol) might provide higher incomes, but might also affect food security both at the national and the local level.

Studies have predicted that sugarcane expansion (for ethanol) will reduce energy exports due to changes in exchange rates, but will increase food availability at the national level having a positive impact on national food security (Maltsoglou and Khwaja, 2010). Another national level study found that increasing women's participation in national biofuel programmes (jatropha and sugarcane) increases food-fuel tradeoffs (Arndt et al., 2011). Women are typically responsible for food production (see below) so their increased participation leads to higher food prices and potential decrease in national food security. The study concluded that "modest improvements in women's education and food crop yields are needed to address food security concerns and ensure broader-based benefits from biofuels investments" (Arndt et al., 2011: 1649). It should be noted that such national level studies rest on numerous assumptions and their results should always be interpreted with caution.

Impacts on local/household food security can also be variable depending on the context of production. For instance, in Tanzania, land provisionally targeted for sugarcane conversion in the Wami Basin is reported to be already under rice production by thousands of smallholders. Up to one thousand rice farmers may have been evicted as a result of the project, yet it was suggested that paid labour in these plantations may have increased rural incomes, helping thus to overcome the precarious food security state of the region (Arvidson et al., 2009). However there are concerns that if water consumption and water pollution are not well managed, there could be negative impacts to the estuarine fish populations, which are the main protein source of the local population (Arvidson et al., 2009).

The Kenyan Mumias Sugar Company (Section 4.4.1) farmers gave the opportunity to cultivate other cash crops, but the relatively high profit margins from sugarcane cultivation led to sugarcane's complete dominance at the expense of other food crops. This led to profound changes in household dynamics. Subsistence food production is predominantly a female activity (see above), while cash crop cultivation is largely a male activity. This shift not only did it marginalize women within the household, but in many cases resulted in cash incomes not being used to buy sufficient food for the household (Tyler, 2007). Widespread adoption of sugarcane cultivation led to almost identical processes in Swaziland, where the government actively promoted irrigation-based, commercial agricultural production among smallholders (to the expense of rain-fed subsistence farming) (FAO, 2008). Furthermore, it was observed that this excessive dependency on a single cash crop exposed many smallholders to external shocks, such as fluctuations in the price of sugarcane and of production inputs.

4.4.4 Health

Certain tasks in the sugarcane sector entail long hours of physically arduous work. For example, cane cutters make an average of 30 scythe blows per minute over a working day extending for 10–12 hours (Abramovay, 2008). Studies have reported the negative health effects, sometimes leading to death, associated with such highly intensive manual tasks (Martinelli and Filoso, 2008). Also, approximately 70 working accidents are reported daily in Brazil, mostly in areas with limited mechanization such as the Northeast (Reporter Brasil, 2009).

Sugarcane production can also have negative effects on public health at the local/regional level. Hospital admissions (particularly for children) due to respiratory problems increase two-to-three times during the sugarcane harvest season in parts of Sao Paulo State where sugarcane burning is still performed (Cancado et al., 2006; Uriarte et al., 2009). A number of acute and chronic health symptoms have also been associated with short- and long-term exposure to pesticides used in sugarcane cultivation (Lehtonen, 2010). Bad application practices have in some cases resulted in water/soil contamination, poisoning and death (Smeets et al., 2008).

A major health hazard in Africa is indoor air pollution from cooking in conventional biomass stoves (Section 3.4.4). It has been shown that switching to ethanol stoves can reduce emission of hazardous indoor pollutants (e.g. PM, CO) and have significant benefits to human health at the household level. Ethanol stoves have already been deployed in several Sub-Saharan countries, including Ethiopia, Tanzania and Mozambique (Takama et al., 2011). Ethanol gel and straight ethanol burn with a carbon-free flame, which, therefore, does not cause the respiratory problems associated with paraffin, charcoal, and firewood (UNDESA, 2007).

4.4.5 Land tenure and social conflicts

The Brazilian sugarcane sector has been historically marked by disputes between landowners and workers over the workers' access to land. Until the late 1960s, sugarcane mills catered to the workforce's needs as the workers had their dwellings inside the mill or on the farm premises, where they also grew their own food. However, in the 1950s there was a massive expulsion of workers from their homes, which essentially eliminated the access of poor plantation workers to housing and to areas suitable for food production (Abramovay, 2008). Additionally, it further restricted land ownership to a few large landowners, further increasing the high land concentration that was a key characteristic of the sector to begin with. As a result, the apparent lack of recent land tenure conflicts in Sao Paulo State can be attributed to this prior consolidation of land into the hands of a few large landowners (Smeets et al., 2008).

An interesting recent phenomenon is the increasing trends of land leasing (by family farmers) to large sugarcane plantations. Ramos (2006) shows that a settler leasing a 15-ha plot in the municipality of Promissao (Sao Paulo State) earns an income of nearly BRL 500 per ha, for a six-year contract. During this time the farmer ceases any other farming activity whatsoever on the leased plot, but hardly any other farming activity would be as profitable for the farmer. Even though such lease contracts are frequent in the pulp and paper industry, in the case of sugarcane, the crop occupies the entire plot so the farmer has to lease the entire plot rather than only part of it. As a consequence, Novo et al. (2010) report a fourfold increase in the price of agricultural land in Sao Paulo State since 1999. They attribute this, to a large extent, to sugarcane expansion.

As discussed in Section 3.4.5, there is a very real threat of farmers being displaced or losing their land tenure rights to large-scale sugar plantations. This is exacerbated by the current tenure regimes (3.4.5) and the prevailing nature of sugarcane production that is based on extensive monocultures located in the vicinity of a sugar mill (Section 4.3).

In Africa, the number of land acquisition requests for sugarcane-based projects is still less than that of jatropha. This is possibly because sugarcane projects require far greater investment due to the need to link closely production and processing. For instance only two out of 24 large-scale land acquisitions requests in Tanzania were aimed at sugarcane production (Sulle and Nelson, 2009).

In the case of the SEKAB project, two extensive areas (400,000 ha and 24, 500 ha) were originally requested (Sulle and Nelson, 2009). This was later substantially reduced, and EcoEnergy which bought out the SEKAB project is only aiming to plant 8,000 ha on the original 24,500 ha concession with outgrowers being used for the balance of the project (EcoEnergy, 2012). As it was initially envisaged, the SEKAB project would have entailed a substantial amount of community land being transferred to SEKAB for sugar production. Some villages had committed almost all of their land to such sugar projects (Sulle and Nelson, 2009), Section 4.3. The Procana project in southern Mozambique would have also displaced a large amount of people that had already been displaced from the Limpopo trans-frontier park and who had been given land in the area that Procana would have occupied (IRIN, 2007).

5. Linking ecosystem services impacts to human well-being and poverty alleviation

As discussed extensively in this report jatropha and sugarcane landscapes can provide, displace, divert and degrade a large number of provisioning, regulating and potentially cultural ecosystem services. These ecosystem services can have a direct positive or negative effect on human well-being at different scales (local, national, global) (Figure 2). Tables 11–22 summarize the main ecosystem services and human well-being impacts associated with jatropha and sugarcane landscapes as identified in this report.

In order to unravel the mechanisms through which the ecosystem services provided, displaced, diverted and degraded by biofuel landscapes in Africa affect human well-being and poverty alleviation we conducted a meta-analysis of key published literature. For jatropha landscapes we identified and reviewed in depth 40 studies from across Africa. The reviewed literature covered the main modes of jatropha production (Figure 1). For the benefit of the reader we include the review templates for five of the reviewed studies in the Appendix. On the other hand there is very limited literature about sugarcane landscapes. As a result we were unable to conduct a similar in depth meta-analysis for sugarcane ethanol in the African context. However the existing literature reviewed in Section 4 and summarized in Tables 11-22 suggests that the mechanisms that were observed in jatropha landscapes are also observed and in sugarcane landscapes in Africa.

Most of the reviewed literature was concerned with just a few of the ecosystem services associated with biofuels. The ecosystem service that was treated in almost every publication in the African context was feedstock/fuel provision (provisioning service). Competition with other provisioning services such as food (and to a lesser extent with feed/fibre) was also a recurring theme in most publications. Other important services such as impacts on freshwater services (e.g. water use, water pollution), climate regulation and erosion regulation occurred in just a handful of dedicated publications. On the contrary no publication treated topics related to cultural ecosystem services. It should also be mentioned at this point that none of the reviewed publications employed the ecosystem services approach. In fact to the authors best knowledge no publication has used the ecosystem services approach to study biofuel landscapes (Gasparatos et al., 2011; 2012b) despite its trasdisciplinary focus, its ability to capture all major biofuel impacts, its ability to link ecosystem change to human well-being and its acceptability by academics, practitioners and policy makers (Section 2). This is indeed a major research gap, Section 6.

The mechanisms through which biofuel landscapes affect human well-being and alleviate poverty (and the magnitude of this effect) greatly depend on the mode of production (Figure 1, Tables 11–22) and the environmental and socioeconomic context within which biofuel production and use takes place.

Table 11: Mechanism and magnitude of fuel provision from jatropha and sugarcane landscapes.

Ecosystem Service	**Mechanism**	**Biofuel**	**Magnitude**	**Comments**
Fuel and fuel feedstock	Biofuel landscapes ***provide*** feedstock that can be transformed into liquid fuel such as bioethanol, biodiesel or straight vegetable oil. The fuel can be blended with transport fuel or be used for cooking, lighting and power generation.	**Jatropha** ***Section 3.2.1.1***	**Moderate** fuel provision potential	**(+)** Jatropha biodiesel and straight jatropha oil exhibit moderately high EROIs. Several studies have assumed optimistic jatropha yields so LCAs for jatropha-derived fuels might overestimate the obtained EROIs. Few complete LCAs for Africa
		Sugarcane **Section 4.2.1.1**	**High** fuel provision potential	**(+)** Sugarcane ethanol exhibits the highest EROIs between first-generation biofuels. Electricity co-generation from bagasse combustion can increase energy provision from sugarcane ethanol production. Few complete LCAs for Africa

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 12: Mechanism and magnitude of food/feed/fibre displacement from jatropha and sugarcane landscapes.

Ecosystem Service	Biofuel	Mechanism	Magnitude	Comments
Food, feed, fibre	**Jatropha** ***Section 3.2.1.2***	Jatropha is a non-edible and non-fibrous plant. Jatropha production can ***displace indirectly*** food, feed and fibre production through competition for land, labour, water and other agricultural inputs.	**Variable** level of displacement in Africa	Studies have reached very different conclusions regarding the food/feed/fibre displacement effects of jatropha production in Africa. Such effects can depend on a number of factors such as the mode of biofuel/feedstock production (Figure 1) and the environmental and socioeconomic context of jatropha production.
	Sugarcane ***Section 4.2.1.2***	Sugarcane is a crop that is used extensively in the food industry. Sugarcane production (for ethanol) can ***displace directly*** food production by diverting sugarcane to fuel production (rather than sugar production for food purposes). Sugarcane production (for ethanol) can ***displace indirectly*** food, feed and fibre production through competition for land, labour, water and other agricultural inputs.	**Low** level of displacement in Brazil **Unknown** level of displacement in Africa	Low-productivity pastureland and, to a lesser extent, peanut and rice cultivation were the main land categories converted to sugarcane in Sao Paulo State (for ethanol production). Displacement effects to other crops were low. Food production displacement might manifest in Africa. However there are very few studies so the scale of potential displacement effects is generally unknown.

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 13: Mechanism and magnitude of water diversion and degradation from jatropha and sugarcane landscapes.

Ecosystem Service	Mechanisms	Biofuel	Magnitude	Comments
Water	Water is required for feedstock cultivation (mainly), feedstock processing and biofuel production. This water can be ***diverted*** from other human (e.g. food production, human consumption) or natural uses. In irrigated landscapes water diversion is expected to be much higher than in rain fed agriculture.	**Jatropha** ***Section 3.2.1.3***	**Low** levels of water diversion	**(+)** Jatropha is a moderate water user when compared to natural vegetation and other agricultural activities in Africa.
		Sugarcane ***Section 4.2.1.3***	**Moderate** levels of water diversion	**(+)** Most sugarcane cultivation in Brazil and Africa is rain fed so it is not expected to divert significant amounts of water from other uses.
	Feedstock production (agricultural phase) might require the application of fertilizers and agrochemicals. Run-off from biofuel landscapes can pollute water bodies. Feedstock processing and biofuel production can produce water-polluting effluents. These activities can ***degrade*** freshwater services.	**Jatropha** ***Section 3.2.1.3***	**Unknown** level of degradation	No studies have been conducted to show the water pollution impacts of jatropha landscapes in Africa or elsewhere.
		Sugarcane ***Section 4.2.1.3***	**Moderate** to high level of degradation	**(-)** Sugarcane cultivation in Brazil has been associated with water pollution in catchments that contain sugarcane plantations and sugar mills. Few studies for Africa so the scale of potential water degradation effects is generally unknown.

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 14: Mechanism and magnitude of climate regulation from jatropha and sugarcane landscapes.

Ecosystem Service	Mechanism	Biofuel	Magnitude	Comments
Climate regulation	Fuel combustion is a major source of GHGs. Biofuel landscapes can ***provide*** climate regulation benefits if the fuel they provide has lower GHG emissions during its whole life cycle than conventional fossil fuels.	**Jatropha** ***Section 3.2.2.1***	**Moderate to low** provision of mitigation benefits	**(+)** Jatropha biodiesel and straight jatropha oil exhibit moderate GHG emission savings when compared to fossil fuels. Several studies have assumed optimistic jatropha yields so LCAs for jatropha-derived fuels might overestimate the anticipated GHG emission savings. **(-)** If LUCC effects are considered then jatropha-derived fuels can have significant carbon debts that might take several decades to repay. Few complete LCA and carbon debt studies for Africa
		Sugarcane ***Section 4.2.2.1***	**High to moderate** provision of mitigation benefits	**(+)** Sugarcane ethanol exhibits very high GHG emission savings among first-generation biofuels. **(-)** If LUCC effects are considered then sugarcane ethanol can also exhibit carbon debts, which are, however, much lower than those of other biofuels. Few complete LCAs and carbon debt studies for Africa

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 15: Mechanism and magnitude of air quality regulation from jatropha and sugarcane landscapes.

Ecosystem Service	Mechanism	Biofuel	Magnitude	Comments
Air quality regulation	Fuel combustion is a major source of atmospheric pollution. Biofuel landscapes can ***provide*** air quality regulation benefits if the fuel they provide has lower air pollutant emissions during its whole life-cycle than conventional fossil fuel	**Jatropha** ***Section 3.2.2.2***	***Unknown*** levels of emissions	Few studies about atmospheric emissions from jatropha biodiesel or straight jatropha oil. Jatropha seedcake briquette combustion results in higher levels of emissions for some pollutants and lower levels for others (when compared to charcoal). It is highly likely that as in the case of sugarcane ethanol (see below) and other biofuels that pollutant emission trends will depend on the pollutant studied.
		Sugarcane ***Section 4.2.2.2***	***Variable*** levels of emissions in Brazil Life cycle emissions might depend on pollutant	**(+)** Emission factors from vehicles running on ethanol or ethanol/ gasoline blends have been decreasing for carbon monoxide (CO), nitrogen oxides (NOx) and sulphur dioxide (SO_2) since the 1980s. **(-)** For some pollutants (e.g. PM2.5, PM10), life-cycle emissions of sugarcane ethanol are higher than those of conventional transport fuel and are usually dominated by the agricultural phase (agricultural burning in particular). No such LCAs for the African contexts. Sugarcane ethanol-influenced transport fleet renewal might potentially introduce cleaner vehicle technology in Africa but this has yet to be proved or modeled. **(+)** Lower emissions from ethanol stoves can result to public health benefits due to reduced indoor air pollution (Section 4.4.4).

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 16: Mechanism and magnitude of erosion regulation from jatropha and sugarcane landscapes.

Ecosystem Service	Mechanism	Biofuel	Magnitude	Comments
Erosion regulation	Agricultural landscapes have extensive areas of bare soil exposed to rain and wind particularly during the initial land conversion stage and the period between harvest and regrowth. Agricultural landscapes that can fix soil or minimize soil loss ***provide*** erosion regulation services.	**Jatropha** ***Section 3.2.2.3***	**Moderate to high** provision of soil protection	**(+)** As a tree species, jatropha does not need to be planted annually. This suggests a lower overall time of bare/exposed soils due to harvesting and regrowth than annual or perennial crops. **(+)** Jatropha's root system may help bind soil. However, no reports could be found verifying or quantifying the soil erosion control benefits of jatropha. **(+)** Jatropha can be used to protect fields from livestock due to its relatively rapid rate and unpalitiability.
		Sugarcane ***Section 4.2.2.3***	**Low** provision of soil protection	**(-)** Erosion rates in sugarcane landscapes are 5.2 times higher than soil formation rates. This is one of the highest soil erosion rates among first-generation biofuels. Few complete studies for Africa

Note: (+) denotes positive ecosystem services impacts while (-) negative ecosystem services impacts

Table 17: Biodiversity impacts from jatropha and sugarcane landscapes.

Impact	Mechanism	Biofuel	Magnitude of effect	Comments
Biodiversity	Biofuel production and use can be directly linked to four drivers of biodiversity loss; **habitat destruction, pollution, climate change and invasiveness** Of these, biofuel-induced habitat destruction is considered as the most important threat to biodiversity. The magnitude of biodiversity loss depends on the type of land that was converted for feedstock production. The conversion of natural ecosystems (e.g., grassland, forest) might result in higher levels of biodiversity loss when compared to the conversion of cultivated land (Fischer et al., 2009).	**Jatropha** ***Section 3.3***	**Unknown** level of impact on biodiversity	No biodiversity surveys conducted in jatropha landscapes in Africa or elsewhere. Our knowledge about species occurrence in jatropha landscapes when compared to surrounding ecosystems is very incomplete. Four different LUCC types have been linked to jatropha landscapes. Of these, the conversion of natural habitats to jatropha landscapes is likely to have the most severe impacts. There have been some reports of jatropha projects resulting in deforestation. Jatropha has been associated with invasive behavior in parts of Australia. Its invasiveness is still uncertain in the African context, as there can be a lag between species introduction and the manifestation of invasive behavior. On these grounds South Africa has chosen to ban jatropha cultivation within the country but most other African countries have chosen to allow it.
		Sugarcane ***Section 4.3***	**Can have a significant** impact on biodiversity loss in Brazil.	Extensive sugarcane monocultures are known to support a relatively limited number of species. An estimated 75% of biodiverse riparian buffer zones in Sao Paulo State have been converted to sugarcane and pasture. Some models predict that sugarcane expansion in the Brazilian Southeast might trigger indirect LUCC effects and push the agricultural frontier in the Cerrado and the Amazon which might potentially lead to significant biodiversity loss in these two highly biodiverse biomes. Water pollution from sugarcane plantations and mills can also contribute to biodiversity loss in riparian ecosystems in Sao Paulo State.

Table 17: Biodiversity impacts from jatropha and sugarcane landscapes. (Continued)

Impact	Mechanism	Biofuel	Magnitude of effect	Comments
			Unknown level of biodiversity loss in Africa	Sugarcane projects in Africa might involve relatively large-scale clearing of indigenous vegetation potentially having a negative impact on biodiversity. Substantive degradation of biodiversity might already been taking place in the absence of biofuel expansion in targeted areas, as local communities can be highly dependent on resources obtained from local ecosystems. This means that sugarcane expansion apart from **direct** biodiversity impacts due to LUCC effects, can **indirectly** affect biodiversity through overexploitation of commercially valuable species on the remaining communal woodlands and forests not converted to sugarcane. There is a real potential to reduce deforestation through the promotion of ethanol gel for cooking. Urban charcoal demand drives the expansion of the rural charcoal sector and, as a consequence, deforestation. Switching cooking fuel into ethanol could potentially decrease deforestation pressure and have significant biodiversity benefits. Few studies for Africa

Table 18: Rural development impacts from jatropha and sugarcane landscapes

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
Rural development ***MA constituent of HW*** Security Basic materials for a good life Health	Jatropha production can offer employment and income opportunities that can manifest: ***directly*** through paid work in plantations, contracted production of feedstock from smallholder farmers or up-skilling opportunities. ***indirectly*** through jatropha-based rural electrification projects that can provide new business opportunities or catalyze the development of better paid jobs locally	**Jatropha** ***Section 3.4.1***	**Variable contribution** to rural development Depends on mode and context of production	Different employment generation potential at the national level depending on the mode of production. National programmes based on smallholders and outgrowers will most likely create higher employment opportunities and economic growth ***(national level impact)*** **(-)** Employment during plantation maintenance phase is likely to be seasonal, rather than permanent. Estimates suggest that the number of new plantations jobs created is fairly low per hectare. Several large-scale jatropha projects have also closed or encountered financial difficulties and have been sold out to new investors. This has further reduced employment opportunities ***(regional level impact)*** **(+)** Salaried work in large-scale plantations is equally, or better, remunerated than other agricultural activities (but are still fairly low for global standards). Such "high" incomes have influenced some rural households to abandon other off-farm income activities. ***(local/household level impact)*** **(-)** Smallholder farmers take considerable risks by converting their entire cash crop production into jatropha. The obtained income is variable. Major determinants of smallholders' income are jatropha seed prices, jatropha yields, the existence of jatropha seed markets and other opportunity costs. ***(local/household level impact)*** **(+)** Jatropha-based soap can provide direct and indirect income benefits. In some cases jatropha soap-making can be a better income generation activity than growing and selling jatropha seeds for fuel ***(local/household level impact)*** **(+)** Some jatropha-based rural electrification projects can create new employment opportunities, increase labour productivity and increase income in rural communities. ***(local/household level impact)***

Table 18: Rural development impacts from jatropha and sugarcane landscapes (Continued)

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
		Sugarcane ***Section 4.4.1***	**Generally positive** for Brazil	In Brazil, smallholder sugarcane production (for ethanol) has practically disappeared, especially in Sao Paulo State. Some of the rural development impacts (and their magnitude) differ by region. **(+)** The sugarcane sector is a major employer, with an estimated 1 million persons involved in the industry as a whole. Most of these jobs are low-skill (e.g., cane cutting) but the technological innovation has boosted high-skill job creation in many regions. Increased mechanization is expected to generate 171,000 high-skilled jobs. ***(national level impact)*** **(-)** Mechanization is expected to eliminate 420,000 low-skill jobs by 2014 in Sao Paulo State alone. Retraining schemes have been planned but it is uncertain how many low-skilled workers will benefit ***(national level impact)*** **(+)** Income from salaried work in the sugarcane sector has increased in absolute terms. The salaries in Sao Paulo's sugarcane plantations are on average higher than those paid in other agricultural sectors. ***(local/household level impact)*** **(-)** In some cases the offered salaries are not high enough to allow workers escape poverty. The structure of the payment scheme combined with the loss of purchasing power in 2008 resulted in several cane-cutter strikes across the state ***(local/household level impact)***
			Unknown (but potentially positive) for Africa	**(+)** The sugar industry is one of the largest employers in East Africa employing directly more than 50,000 employees and indirectly over 300,000 small-scale farmers ***(national level impact)*** **(-)** Outgrower programs in Tanzania, South Africa and Kenya have contributed to the development of a relatively prosperous smallholder sector reducing significantly the number of people gaining less than the minimum wage ***(local/household level impact)*** **(-)**. Large-scale sugar production in Malawi, Mozambique and Zambia might have provided low wages and poor housing. Land rights might have also been poorly negotiated with too informal contracting agreements and unbalanced power between workers in small-scale farming schemes ***(local/household level impact)***

Note: (+) denotes positive human-wellbeing impacts while (-) negative human well-being impacts

Table 19: Energy security impacts from jatropha and sugarcane landscapes

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
Energy security ***MA constituent of HW*** Security Basic materials for a good life	The fuel provided by biofuel landscapes can be blended with transport fuel or used for cooking, lighting and power generation. This can increase energy security at the household, local and national level	**Jatropha** ***Section 3.4.2***	**Low current contribution** to energy security	**(-)** Jatropha biodiesel has not substituted significant amounts of transport fuel in Africa yet, despite several countries enforcing blending mandates ***(national level impact)*** **(+)** Straight jatropha oil has been used in parts of Africa for lighting and power generation from small-scale biofuel projects. If successful some of these projects can provide locally renewable energy for some uses such as lighting and low watt applications, but insufficient for cooking and space heating. Still access to modern energy, even if only in small amounts, can have substantive energy security and rural development benefits ***(local/ household level impact)***
		Sugarcane ***Section 4.4.2***	**High current contribution** to energy security (Brazil)	**(+)** Sugarcane ethanol and electricity cogeneration from bagasse burning provides a significant fraction of the energy consumed within Brazil ***(national level impact)***
			Low current contribution to energy security (Africa)	**(-)** Despite significant ethanol blending in some African countries in the past, ethanol blending is currently is quite low. Bagasse electricity cogeneration is also quite limited apart from Mauritius ***(national level impact)*** **(+)** High sugar productivity in some countries combined with the high costs of importing transport fuel (particularly in landlocked countries) might make it economically viable to meet existing blending mandates from relatively limited land. Electricity co-generation from bagasse might also produce significant amounts of electricity ***(national level impact)***

Note: (+) denotes positive human-wellbeing impacts while (-) negative human well-being impacts

Table 20: Food security impacts from jatropha and sugarcane landscapes

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
Food security ***MA constituent of HW*** Security Basic materials for a good life Health Good social relations	Feedstock production can ***displace*** food production. ***Income provided*** from biofuel-related production activities can be used to buy food. These two mechanisms can have positive or negative impacts on food security at different scales (household, local, national and international)	**Jatropha** ***Section 3.4.3***	**Variable** impact on food security Depends on mode and context of production	Jatropha expansion does not seem to have affected national food security in African countries. Modeling exercises have found varying impacts on national food production due to jatropha expansion ***(national level impact)*** **(-)** Switching from food to jatropha production (for outgrowers/ smallholders) can displace food production and pose a threat to local food production, and as such threaten food security at the household and the local level (***local/household level impacts***) **(+)** Jatropha production can in some cases result directly and indirectly into higher household incomes (Table 18). Higher incomes can increase the food security of households even if there has been a switch from food production to jatropha production (***local/household level impacts***) Jatropha-related, impacts on food security are very difficult to delineate because several studies (particularly at the national level) are based on modeling exercises sometimes making invalid assumptions about jatropha yields.
		Sugarcane ***Section 4.4.3***	**No current impact** on food security within Brazil	**(+)** Food displacement effects in Brazil have been quite moderate (Table 12). National food security does not seem to have been decreased ***(national level impact)*** **(-)** International sugar prices might increase due to sugarcane ethanol expansion in Brazil ***(international level impact)*** **(+)** Food security of workers in the sugarcane sector might have increased due to the higher income usually obtained in the sugarcane/ethanol sectors ***(household level impact)***

Table 20: Food security impacts from jatropha and sugarcane landscapes (Continued)

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
			Variable impact on food security in Africa Depends on mode and context of production	**(+)** Sugarcane expansion (for ethanol) might reduce food exports due to changes in exchange rates, but might increase food availability, and hence food security, at the national level ***(national level impact)*** **(-)** High female involvement in national biofuel programmes might increases food-fuel trade-offs, as women are typically responsible for food production ***(national level impact)*** **(+)** Relatively high profit margins (and as an extension higher incomes) from sugarcane cultivation led, in some areas, to sugarcane's complete dominance at the expensive of other food crops. Paid labour in plantations may increase rural incomes and hence promote the profitability of agricultural activities overcoming the precarious food security levels of certain areas. The above might increase food security due to higher income opportunities ***(household/local level impact)*** **(-)** In some cases the land targeted for sugarcane conversion was already under food production or was located in areas of documented poor food security. Switching from subsistence agriculture to sugarcane might catalyze changes within households and result in cash incomes not being used to buy sufficient food for the household. Excessive dependency on a single cash crop might expose smallholders to external shocks, such as fluctuations in the price of sugarcane and of production inputs. All of the above might decrease food security ***(household/local level impact)***

Note: (+) denotes positive human-wellbeing impacts while (-) negative human well-being impacts

Table 21: Health impacts from jatropha and sugarcane landscapes

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
Health ***MA constituent of HW*** Health	Biofuel production and use can emit air and water pollutants associated with negative impacts to public health. A major public health hazard in Africa is indoor air pollution associated with cooking in conventional biomass stoves (Section 3.4.4).	**Jatropha** ***Section 3.4.4***	Unknown impact on public health for Africa	**(-)** The toxicity of jatropha's seeds, oil and other co-products (e.g., seedcake) can be potentially threatening to human health and caution has been suggested during the production and use of such products particularly in enclosed spaces Studies about the atmospheric emissions of stoves using jatropha seedcake showed increases in emissions for some pollutants and decrease for others (compared to charcoal stoves).
		Sugarcane ***Section 4.4.4***	**Potentially moderate to high** impacts on public health for Brazil	**(-)** Certain tasks in the sugarcane sector entail long hours of physically arduous work. Studies have reported the negative health effects, sometimes leading to death, associated with such highly intensive manual tasks **(-)** Hospital admissions (particularly for children) due to respiratory problems increase two-to-three times during the sugarcane harvest season in parts of Sao Paulo State where sugarcane burning is still performed. A number of acute and chronic health symptoms have been associated with short- and long-term exposure to pesticides used in sugarcane cultivation. Bad application practices have in some cases resulted in water/soil contamination, poisoning and death
			Unknown for Africa	**(+)** Ethanol gel burns with a carbon-free flame, which, therefore, does not cause the respiratory problems associated with paraffin, charcoal, and firewood.

Note: (+) denotes positive human-wellbeing impacts while (-) negative human well-being impacts

Table 22: Land tenure and social conflict impacts from jatropha and sugarcane landscapes

HW impacts	Mechanism	Biofuel	Magnitude of effect	Comments
Land tenure and social conflict ***MA constituent of HW*** Security	In almost every African country expansive rural areas are under customary tenure, with communal use of the rangelands and forests. In legislation, such land is often recognised as 'communal land' with no private ownership. In many African countries communal land is converted to state land during the process of setting up lease agreements with biofuel investors This is a formal process where tenure is permanently transferred to the state, who then leases the land to investors. If a biofuel investment project fails then the land typically remains state land rather than reverting back to the community. Thus a community can potentially lose both their traditional access to land as well as the benefits they had expected to obtain from the failing biofuel projects.	**Jatropha** ***Section 3.4.5***	Cases of **loss of land tenure** in Africa	**(-)** There have been allegations of communities in Tanzania, Mozambique, Ghana, Kenya and Zambia losing access to their communal land. **(-)** Gender inequality issues can limit employment and income benefits to women, due to issues of land ownership. For example, women who are responsible for agricultural labor do not necessarily own the land and therefore do not gain benefits from planting jatropha.
		Sugarcane ***Section 4.4.5***	**Minimal loss of land tenure** in Brazil	**(-)** The Brazilian sugarcane sector has been historically marked by disputes between landowners and workers over the workers' access to land. Land ownership is restricted to a few large landowners. The apparent lack of recent land tenure conflicts in Sao Paulo State can be attributed to prior consolidation of land to a few large landowners. Lately there are several cases of land leasing in Sao Paulo State by family farmers to large sugarcane plantations. Due to the nature of sugarcane cultivation this would preclude any other farming activity in the leased land.
			Potentially significant future land tenure impacts in Africa	**(-)** There is a very real threat of peasant farmers being displaced due to large-scale sugar plantations, and this is exacerbated by the current tenure regimes and the prevailing nature of sugarcane projects (i.e. extensive plantations centred around sugar-mills). Relatively few land acquisition requests for sugarcane-based projects. In some of these projects, some villages committed almost their land. There are reports of sugarcane projects that would have displaced people if they proceeded.

Note: (+) denotes positive human-wellbeing impacts while (-) negative human well-being impacts

The main mechanism through which biofuel landscapes can affect human well-being and become agents of rural poverty alleviation is by ***providing*** feedstock[29] that can be used for fuel production (provisioning ecosystem service) (Table 11). This feedstock can be sold to external markets providing in the process employment and income opportunities to persons linked with formal contracts to large biofuel projects (e.g. salaried workers or outgrowers) or to individual feedstock producers (i.e. smallholder farmers) (Table 18). Through the generation of such employment/income opportunities, biofuel landscapes become a **direct** agent of poverty alleviation. Sometimes locally produced biofuel can be used by local communities to meet their energy demands (Table 19). This locally produced and consumed fuel can catalyze the creation of jobs outside the feedstock production sector (e.g. manufacturing jobs within the local community) or allow people to spend more time in other productive activities (e.g. having decent light to work at night, reduced labour to mill maize, allow the use of electric sewing machines to increase labour productivity) (Table 18). In addition it can reduce expenditure on imported products such as candles and paraffin, effectively circulating money within the community rather than having it leave the community. This can be considered as rather **indirect** mechanism of rural poverty alleviation mediated by biofuel landscapes.

While providing their main provisioning service (feedstock/fuel), biofuel landscapes can ***displace*** directly and indirectly other provisioning services such as food, feed and fibre (Table 12). If the displaced services provide lower income opportunities to local populations than those obtained from biofuel landscapes (see previous paragraph) then it can be inferred that biofuel landscape can alleviate poverty. If the opposite phenomenon takes place (i.e. displaced services provide higher income opportunities than the services provided by biofuel landscapes) then biofuel landscapes can induce poverty.

Finally biofuel landscapes can ***divert*** other ecosystem services from their original use to feedstock/fuel production. The main relevant service in this category is water (Table 13). As mentioned jatropha (Sections 3.2.1.3) and sugarcane (Sections 4.2.1.3) landscapes are relatively modest water users in Africa when compared to native vegetation and other agricultural activities. As a result in rain-fed agricultural systems biofuel landscapes are not expected to divert significant amounts of water from other human activities (agriculture, human consumption) or natural ecosystems. On the other hand, diversion of water to biofuel landscapes in irrigated agricultural settings can induce indirect competition with other productive activities (food, feed and fibre) by reducing the provision of freshwater services to them. This can have a negative impact on the provision of these ecosystem services from surrounding landscapes and as such potentially contribute negatively on human well-being and induce poverty (Table 18).

Of the six drivers of biodiversity loss identified in the MA[30] , biofuels can be **directly** linked o four; habitat destruction, pollution, climate change and invasiveness (Gaparatos et al., 2011), Table 17. The impact of biofuel production on climate change (Section 3.2.2.1 and 4.2.2.1), pollution (Sections 3.2.1.3, 3.2.2.2, 4.2.1.3 and 4.2.2.2) and invasiveness (Section 3.3) has already been discussed. Biofuel-induced habitat destruction is considered as perhaps the most important threat to biodiversity (Fischer et al., 2009). Generally speaking the magnitude of biodiversity loss from direct and indirect LUCC effects depends on the type of land that was converted for feedstock production. The conversion of natural ecosystems (e.g., grassland, forest) might result in higher levels of biodiversity loss when compared to the conversion of cultivated land (Section 3.3 and 4.3). Biofuels can also be **indirectly** linked with another of the MA drivers of biodiversity loss; overexploitation. There have been

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[29] Other co-products such as jatropha-derived soap and jatropha seedcake can also contribute to rural development, but to a much lower extent in most African contexts.

[30] Biodiversity loss has been linked to habitat destruction, overexploitation, pollution, climate change, invasive species and disease (MA, 2005b).

cases of relatively undisturbed ecosystems used by local populations to obtain ecosystem services[31] being converted into biofuel landscapes. If such human activities were displaced in smaller areas then they could be perhaps intensified and result in the loss of commercially valuable species.

Our meta-analysis of the jatropha literature found that yields seem to be the single most important factor affecting the magnitude of most human well-being and poverty alleviation effects associated with jatropha landscapes. In a nutshell high jatropha yields in Type 3 and 4 projects (Figure 1) can be translated to higher income generation potential and as a result to higher direct poverty alleviation potential. High yields can also translate into higher energy provision potential from small-scale biofuel projects (Type 1 projects, Figure 1) and as a result into higher indirect poverty alleviation potential. High yields can also translate into higher climate regulation benefits from jatropha landscapes.

However, the fact that jatropha is effectively a wild (un-domesticated) crop with unknown yield potential underpins many of the uncertainties associated with its production. Our meta-analysis shows that most studies that aimed to link jatropha production and human well-being, used assumptions for the expected yields. To make matters worse these assumptions were mostly rather optimistic, resulting in an inflation of the anticipated benefits. Predictions of high social benefit, especially in terms of income generation have, to date, largely not been observed.

Another point emerging from our review is the dispelling of the myth that jatropha is a crop suited for arid and semi-arid areas. Like most crops, jatropha performs best when grown on good soils with adequate fertilizer and soil moisture. Though it may survive in poor soils, this tends to have negative impacts on yields. Literature suggests that meaningful yields will be realized only in areas with some rainfall, with peak yields being possible at about 1,500 mm per year. The data underpinning these yield predictions is still, however, quite tentative as there have been just a few such studies conducted so far. Still, jatropha grown on poor soils might still provide valuable ecosystem services such as soil stabilization, although this is only supported by anecdotal evidence.

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[31] e.g. fuelwood, timber, non-timber forest products and wild animals/plants for food.

6. Research gaps

Gap 1: Understand how biofuel landscapes provide or compromise ecosystem services.

In view of the plans for biofuel expansion in Africa, there should be significant research efforts to better understand the mechanisms through which the different biofuel landscapes in the continent provide, displace, divert and degrade ecosystem services. At the moment our understanding of these issues in Africa is rather limited. A much better understanding will be needed before designing biofuel landscapes that can maximize fuel output without compromising biodiversity and the services it provides (Gap 6).

As most studies in Africa have focused on fuel/food/water provision and climate regulation services a good starting point will be to get a better understanding of how different modes of biofuel production (Figure 1) affect such services. At the same time we also need to gradually start studying impacts on services not well represented in current studies such as pollination, erosion regulation and cultural services.

It should be noted that while more focused studies could be sufficient to get an understanding of individual impacts, integrated studies (see Gap 4) would be increasingly required if we are to understand better ecosystem services trade-offs in biofuel landscapes.

Gap 2: Unravel the mechanisms through which these ecosystem services link to human well-being and contribute to poverty alleviation

Research will be needed to unravel the mechanisms through which the ecosystem services provided, displaced, diverted and degraded by biofuel landscapes are linked to human well-being and how they can contribute to poverty alleviation. Only when we understand these mechanisms it will be possible to fully appreciate the promise and pitfalls of biofuel production and use in Africa and beyond.

The meta-analysis discussed in Section 5 has been a first step towards this end. First of all similar meta-analyses of the latest available evidence have to be conducted for other feedstocks in other regions of the world. Such meta-analyses can be ideal for identifying specific knowledge gaps and for forming hypotheses about the nature of these mechanisms. Substantial empirical research will be then needed to establish such links for the different biofuel practices in Africa and beyond.

Gap 3: Establish the biodiversity impacts of biofuel landscapes in Africa

The studies reviewed in this report suggest a very poor understanding of the impact of biofuel landscapes on biodiversity and deforestation in Africa. To our best knowledge there have not been any biodiversity surveys in jatropha landscapes of Africa. First of all, biodiversity surveys in biofuel landscapes and adjacent ecosystems must be conducted in order to identify the relative occurrence of different species. This will be beneficial for establishing a knowledge baseline about the potential scale of biodiversity loss due to conversion in biofuel landscapes. It will be beneficial for such surveys to cover the different types of biofuel projects (Figure 1) so as to get a better understanding of their different impacts on biodiversity.

Research will then be needed to establish the mechanisms through which different biofuel production modes affect biodiversity in the African context, and how these impacts can be minimized. For example small-scale farming (Type 1 and 3 projects, Figure 1) often results in lower obtained yields. This may result in larger areas being converted for feedstock production. On several occasions smallholder projects might form a mosaic of converted land within a matrix of a more natural (but partly degraded) landscape. On the other hand large-scale plantations (Type 4 projects, Figure 1) tend to convert much larger blocks of land and use destructive management practices (e.g. large quantities of agrochemicals). However, through the designation of HCV areas, they might also ensure that ecologically important habitats within their estate are conserved. The impacts of such landscape features and management practices on biodiversity need to be understood if more biodiversity friendly landscapes in Africa are to be developed (Gap 6).

In any case when assessing such biodiversity impacts it is important to consider what the impacts would have been if the biofuel projects had not been implemented. Large-scale deforestation is taking place in most African countries as a consequence of population increase, agricultural expansion and fuelwood and charcoal extraction. Only through such comparisons it would be possible to identify the least damaging development strategies across the continent.

Gap 4: Develop and apply integrated assessments tools in biofuel landscapes

Our reading of the biofuel literature suggests not only an incomplete understanding of the ecosystem services provided, displaced, diverted and degraded by biofuel landscapes in Africa but also a piecemeal understanding. There are few, if any, studies that have provided an integrated assessment of the impacts of jatropha and sugarcane landscapes in Africa. This lack of integrated assessment of biofuel impacts is a common occurrence and for other biofuel practices in other parts of the world. This is largely due to the lack of appropriate robust integrated assessment tools that can be used in biofuel landscapes (Gasparatos et al., 2011).

An important research task for the future is to develop integrated assessment mechanisms fit for biofuel landscapes. Such tools need to be able to provide a robust and integrated assessment of the many impacts associated with biofuel production and use. They should also be able to consider different scenarios and provide rapid assessment in a cheap and user-friendly manner if they are to be adopted by the biofuel industry or practitioners working on biofuel certification.

Development of such tools could enhance the quality of the information used during the planning and certification of biofuel projects and as such have a ripple effect on the conservation of ecologically important areas.

Gap 5: Synthesize the biofuel impacts literatures using the ecosystem services approach

Despite the huge increase in biofuel-related literature, there are virtually no studies that have used the ecosystem services approach to synthesize the existing knowledge about biofuel impacts (Gasparatos et al., 2011; 2012b). Nevertheless it has been suggested that the ecosystem services approach offers several benefits towards this end (Gasparatos et al., 2012b), Section 2. This report had provided a comprehensive synthesis of the evidence related to jatropha/sugarcane landscapes in Africa. Similar exercises should be carried and for other feedstocks in other regions of the world.

Gap 6: Develop and assess the effectiveness of multifunctional and biodiversity-friendly biofuel landscapes

It has been suggested that feedstock cultivation methods not relying on extensive monoculture (e.g., Tilman et al., 2006), are multifunctional or employ land sparing and wildlife- friendly farming techniques (e.g. Koh et al., 2009) can have a lower negative impact on biodiversity. However very little research has been conducted regarding the benefits that such biofuel landscapes might offer in the African context.

Future research must identify potential biodiversity and ecosystem services related benefits of such production models that need nevertheless to be sensitive to the ecological and human realities of Africa,

Gap 7: Determine the factors that affect jatropha yields

Yield remains a key constraint to a viable jatropha industry. Research is needed to understand the anticipated jatropha yields under different agro-ecological conditions and management practices across Africa. A good knowledge about the factors that influence jatropha yields can give hints about the potential viability of jatropha policies/projects. As such they can be of importance to policy makers and project developers involved in the jatropha sector.

Research on developing improved jatropha varieties through conventional breeding will be further needed. These varieties will need to be more suited in the different agro-ecological zones of Africa if they are to offer better and proven yield prospects.

Gap 8: Assess alternative biofuel feedstocks for Africa

Given the poor performance of jatropha to date, the potential of other feedstocks may well be higher in parts of Africa. Palm oil might have a high potential (though a relatively limited range) in West and East Africa. There is also a growing interest in the use of sweet sorghum, as it appears to have a higher potential than sugarcane in the slightly drier areas of Africa. In South Africa some farmers have had substantial success with sugar beet. The production potential of second-generation biofuel (including from agricultural/ forestry waste) is also great across the continent but their use is hampered by poor infrastructure and research and development (IEA, 2010). Research will be needed to establish the production potential, viability and impacts of the promising alternative biofuel feedstocks in Africa.

7. Policy recommendations

Various actors with different vested interests are involved in biofuel chains. Yet the fact remains that biofuels in Africa can entail very different production practices taking place in vastly different ecosystems. Crucially the different reasons (drivers) and biofuel impacts vary significantly between areas. Further to local environmental and socioeconomic context it is fair to say that in most cases the difference on whether biofuels provide a net-benefit to the environment and human well-being also depends on the technological processes and the policy instruments adopted during biofuel production, use and trade (Gasparatos et al., 2011). In this respect, the impacts and tradeoffs of large-scale sugarcane bioethanol production for export are quite different from those of small-scale jatropha biodiesel production for local consumption. These are only some of the reasons that can render biofuel policy-making a rather complicated politically charged topic.

As a result it would be impossible, counterproductive and dangerous, to provide silver-bullet type of policy recommendations in this report. Instead we offer a list of policy recommendations that are sensible considering the currently ambiguous, incomplete and highly context-specific knowledge about biofuel impacts across Africa as discussed throughout this report.

In any case, we cannot stress enough how important it is for policymakers to understand the national and local context within which biofuel production and use is going to take place. Understanding this context, the competing interests at stake and the tradeoffs of biofuel production and use can go a long way toward designing effective policies.

Recommendation 1: Adopt biofuel policies that reflect national realities and are compatible with wider policy objectives

At the moment feedstock/biofuel production in Africa is primarily taking place for export and secondarily for enhancing energy security, e.g. through the substitution of conventional transport fuel or rural electrification. Environmental concerns (e.g. GHG savings or air quality improvement) are not featuring as important drivers of biofuel production across the continent (Section 1.2.1).

At the national level it is important for the governments of those African countries that are (or will be) putting biofuel policies into place, to determine biofuels' true contribution not only to national energy security but also to wider national economy and human development goals. Tradeoffs may well be needed between these national priorities.

Meeting national level needs (e.g. through increasing biofuel use at the transport sector) whilst still maintaining rural energy poverty would be a travesty and mechanisms are needed to ensure that the rural poor also benefit from improved energy options. For example, there are contexts where biofuels could be better used to directly meet the local rural fuel needs rather than being produced for export or to meet domestic blending mandates (Section 3.4.1, 3.4.2, 4.4.1, 4.4.2). In such contexts biofuels can offer a larger benefit to national energy security by tackling urgent local needs of urban and rural populations rather than being used in the transport sector (Box 2).

Tackling such local energy concerns can sometimes reduce pressure to local ecosystems. For example increased use of modern ethanol stoves can displace conventional wood/charcoal stoves that cause deforestation (Section 4.3) and/or indoor pollution (Section 4.4.4). Such environmental and social co-benefits should be identified and promoted to the extent possible through appropriate policy instruments (Recommendation 3, 9).

Box 2: The role of liquid biofuels in Uganda's energy security

Over 500 million people in Sub-Saharan Africa are not connected to electricity grids and rely substantially on solid biomass to meet their energy needs (UNDESA, 2007). For liquid biofuels to be a true part of the energy solution for Africa, biofuel energy systems need to fulfill the needs of the residential sector, which makes up the bulk of final energy demand (44 per cent in 2009). Between 2000 and 2009, the proportion of residential energy needs from solid biomass has remained above 87 per cent (IEA, 2011).

By way of example, we consider Uganda's energy needs. Uganda is unique in its energy use in Africa due to its high biomass dependence when compared to other countries Uganda is a landlocked and fossil fuel-poor country that currently imports all its fuel from Kenyan and Tanzanian ports. The country's oil demand has steadily increased over the past 30 years (EIA, 2012). However, traditional fuels are over-represented in Uganda's energy mix. making up over 80% of the country's energy profile while modern fuels (hydrocarbons and electricity) constitute only 10 per cent. To put this in perspective, the share of traditional biomass and modern energy in Africa's energy profile as a whole is 48 per cent and 50 per cent, respectively (IEA, 2011).

Households are almost entirely dependent upon biomass for energy needs. Urban residents obtain close to 90 per cent of cooking energy from fuelwood, while in rural areas this figure increases to 98 per cent (Knopfle, 2004). Conversely, in its neighbour, Kenya, only around 10 per cent of urban population relies on biomass for cooking (80 per cent in rural areas) (Kenya Ministry of Energy, 2011).

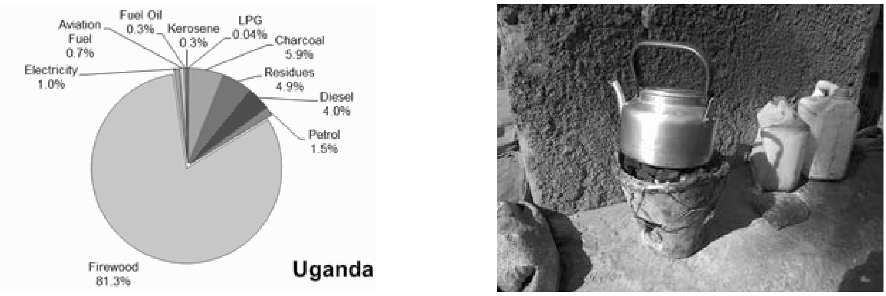

Figure 5 Residential energy demand by fuel in Uganda and charcoal cooking stove used by urban Ugandan households.

Figure Source : Adapted from the Ministry of Energy and Mineral Department, Republic of Uganda (2011)

Photo Source : Author's Own.

While liquid biofuels can have a role in meeting transport and industry energy needs, they have limited use for the household sector, which makes up the bulk of the country's energy demand. To be truly part of Ugandan's energy solution, liquid biofuels need to substitute the country's biomass demand, which is driven to a large extent by household cooking needs.

The vast majority of Ugandan households use rudimentary technology for cooking, comprising little more than three stones and an open fire, or a portable receptacle for combusting solid biomass. Liquid fuels are incompatible with these basic stove types, yet alternative stoves that use liquid fuels are out of reach for most households. Unless liquid biofuels can meet residential sector's energy needs, it will have a limited role in improving Uganda's energy security.

It is important to consider that substituting fuelwood and charcoal with ethanol and other liquid biofuels can have important co-benefits such as reduction in deforestation and improvement in public health.

Recommendation 2: Promote rural development through support to small feedstock producers

Rural development has been a key driver of biofuel expansion across Africa (Section 1.2). It has been discussed that biofuel landscapes can provide feedstock (provisioning service) (Section 3.2.1.1, 4.2.1.1). This activity can boost rural development directly through the generation of employment/income opportunities and indirectly through the provision of locally renewable energy that can boost other productive activities (Table 18–19).

However different feedstocks and different modes of biofuel production can have very different rural development outcomes (Section 3.4.1, 4.4.1). It is important and at the same time challenging to understand which feedstocks and production modes are better fit to tackle rural development issues in Africa.

Our review suggests that large-scale plantations (Type 4 projects, Figure 1) can generally offer higher salaries than other agricultural activities but show greater variability in profitability and success (Section 3.4.1). As a result there are considerable employment and income generation uncertainties and risks for salaried workers and smallholders directly linked to large biofuel projects (Type 3 projects, Figure 1). In some cases higher rural development benefits might be gained by promoting smallholder feedstock production or using jatropha for non-fuel purposes, e.g. soap-making. Finally there are also examples of indirect rural development benefits at the household/ local level via small-scale biofuel projects (Type 1 projects, Figure 1) that have broader flow-on effects to the local economy (Section 3.4.1). In the case of sugarcane ethanol there is a more limited understanding of potential rural development benefits. However there is evidence to suggest that the sugar industry employs a significant amount of people in parts of Africa and there have been some success stories of poverty alleviation through sugarcane production from outgrowers linked to a nuclear estate (Section 4.4.1).

All of the above suggest that there cannot be a silver-bullet suggestion about which biofuel strategy could offer the greatest rural development benefits in a given local context. However there is some consistent evidence to suggest that projects involving small sugarcane/jatropha producers or the local use of jatropha-derived goods (whether for fuel or soap) can offer greater employment and income opportunities (Section 3.4.1, 4.4.1).

That said, there should be effort to develop policies that support small sugarcane/ jatropha producers (smallholder farmers and outgrowers). Even though some large-scale plantations will be necessary to ensure the establishment and stability of biofuel markets (see Recommendation 3), the policy environment should ensure that an active small-producer core supports the biofuel industry. Policy instruments could include small producer quotas, tax relief based on small producer contributions, legislation requiring small producer contributions or market access to national and international markets being dependent on small producer contributions.

There should also be efforts to boost the development of small-scale biofuel projects for decentralized rural electrification in contexts that are considered cost-effective (e.g. in remote areas where fuel imports can be extremely costly) (Section 3.4.2). Small-scale biofuel projects (Type 1 projects, Figure 1) can tackle simultaneously rural development issues and improve local energy security (Section 3.4.1, 3.4.2). Doing so removes the commercial nature of jatropha production as small-scale production for rural development need only recover operating costs (Section 3.4.1), whereas large-scale production will invariably operate with a commercial motive that may concentrate benefits to only a few stakeholders and investors as observed in Brazil (Section 4.4.5).

In any case, policy instruments that promote small-scale feedstock production or biofuel use, should contain safeguards that support will be offered only under the condition that ecologically important areas will not be degraded.

Recommendation 3: Develop viable biofuel / biofuel co-product markets and promote environmentally sound biofuel technologies

Building proper biofuel markets will allow the establishment of stronger links between producers and users and as such reduce risks to producers. Mandates that render the blending of biofuels into conventional fuel as a legal requirement (Section 1.3) is just one way of establishing a steady biofuel demand and increasing the economic viability of biofuel production. However such mandates might not always be the appropriate mechanisms to achieve this.

In those contexts that biofuels are more beneficial for use in cooking devices (ethanol at present), then a different suite of policy instruments will be more appropriate. As already discussed such devices can reduce the demand for environmentally destructive fuels such as charcoal (Section 4.3), benefit public health by decreasing indoor air pollution (Section 4.4.) and potentially generate economic and social benefits as the users will spend less amounts of time to collect their cooking fuel.

Technologies that can demonstrate to meet local needs[32] and offer such environmental and social co-benefits should be promoted through appropriate incentives to their users. Initially it should be ascertained that the technology to be introduced meets local needs, e.g. through initial surveys and consultation with future users. Considering that a key barrier to the effective introduction of the technology can be high capital costs (Tsephel et al., 2009), removing all taxes from stove ethanol (ethanol gel) as well as supporting the distribution of stoves through state-sponsored programmes could boost the penetration of the technology. Persuading large-scale ethanol producers to adopt this as a corporate social responsibility strategy could further facilitate the use of ethanol as a clean cooking fuel.

It is also important to promote the development of markets for the most promising biofuel co-products. Perhaps the most promising biofuel co-product in Africa is electricity produced through bagasse combustion (Section 4.2.1.1).[33] This electricity can be sold to local off-grid customers or as surplus electricity in the national grid as an independent power producer (Batidzirai and Johnson, 2012). The first option would require the provision of incentives to ethanol distilleries to invest in cogeneration technology. The second option would require the development of appropriate national policies that would allow independent power producers to generate and supply electricity to the public network, e.g. through appropriate feed-in tariffs. Another promising co-product is jatropha seedcake for fertilizer, fodder (after detoxification) or methane production (Sections 3.2.1.4, 3.4.1.1, 3.4.2). Finding mechanisms to return this by-product of jatropha fuel production to the actual farmers, rather than having them collect it at the final processing location, might require the subsidization of local oil extraction or other similar incentives.

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[32] In some contexts the introduction of modern stoves has failed because the people receiving them simply did not use them. One of the reasons is that often stove design does not consider user needs.

[33] Another promising sugarcane ethanol co-product is sugarcane residue that can be used as animal feed.

Recommendation 4: Coordinate institutional support and develop an innovation system for sustainable biofuel production

Achieving the development of viable, competitive and environmentally sustainable biofuel and co-product markets (Recommendation 3) will require coordinated action across government, industry and academia. Poor infrastructure is likely to hamper such markets, so ensuring appropriate infrastructure development will be crucial.

This would require the development of intricate policy frameworks (such as Phased Biofuel Development Strategies) across several government ministries (Mitchell, 2011). Such policy frameworks must not only develop the appropriate infrastructure or provide the incentives for biofuel production but must foster technological innovation in both the demand and supply side of the biofuel chain (Puppim de Oliveira, 2002).

Technological innovation will be crucial for unlocking the true potential of jatropha biodiesel and sugarcane ethanol in Africa. Maximising feedstock provision from biofuel landscapes (provisioning service) and optimizing feedstock processing should be key aims of this technological innovation. For example, when the Proalcool programme began in Brazil, each hectare of sugarcane yielded approximately 2,000 liters of ethanol, whereas currently the figure is closer to 6,000 liters (Goldemberg, 2008). This increase in productivity was possible due to the development of new sugarcane varieties that are more suited to Brazil’s weather conditions, the improvement of sugar extraction–vinasse recovery–fermentation and the cogeneration of power using bagasse (Furtado et al., 2011). This was, to a large extent, the direct result of a sectoral innovation system set up in the State of Sao Paulo that has been largely private in nature since the 1990s (Furtado et al., 2011). Another significant factor was innovation in the automotive industry with the development or neat ethanol and flex fuel vehicles (FFVs) (Gasparatos et al., 2012a).

When considering the diverse modes of biofuel production (Figure 1) and the numerous context-specific mechanisms through which biofuel production and use can affect human well-being (Section 5), it appears advantageous to move the focus of policies that promote innovation in the biofuel sector from the model of "technology delivery" to a norm where the "capacity to innovate" is prioritized (Dyer, 2012).[34]

A policy priority for fostering beneficial innovation in the biofuel sector is primarily related to land tenure practices (Section 3.4.5, 4.4.5, Recommendation 7). While less of an innovation in the technical sense (e.g. improvement of seed technology or farming practices), land ownership affects the priorities and investments that are made in the biofuel sector. As such, clarity and consensus in this institutional aspect is a crucial precondition to facilitate beneficial innovation in the biofuels sector.

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[34] In the "technology delivery" model, feedstock farmers are considered as mere recipients of better seeds or knowledge from experts. In this respect, the farmers and their knowledge are considered exogenous to the innovation process. The disadvantage of this approach is that it is a poor enabler of context specific knowledge informing the innovation process. Conversely, the "capacity to innovate" refers to a completely integrated innovation practice that involves all public and private actors for "*creation, diffusion, adaptation and use of all types of knowledge in production and marketing*" (Dyer, 2012: 3). In this approach, the local socioeconomic and environmental context is integrated in a reflexive manner innovation process and can therefore be more responsive to the problems of food security, use rights and tenure practices encountered across parts of Africa that biofuel production is expanding.

Recommendation 5: Base feedstock choices on proper agronomic knowledge

In several parts of Africa there have been significant differences between expected and achieved feedstock yields (particularly for jatropha) (Section 3.4.1). Despite high initial expectations regarding the energy and rural development potential of jatropha projects, the hype about jatropha is beginning to fizzle due to the quite low obtained yields (GTZ, 2009) (Section 3.4.1, 5). Perhaps the key reason behind such unmet expectations has been our poor scientific understanding of the possible yields, and the factors they depend upon, as jatropha has not been extensively cultivated in the past for food or industrial purposes.

That said, the promotion and the allocation of land to jatropha projects should be reconsidered until sufficient data is available to ensure that a jatropha-based biofuel industry will be technically, financially and ecologically viable. Policies should demand national-level testing and stimulate the breeding of new jatropha varieties in order to ensure that planting stock can provide adequate yields (Section 6). Only if jatropha projects can demonstrate that they can be viable should institutional support to establishing a jatropha-based biofuel industry be considered.

As a result if biofuels are indeed identified as the preferred means to support agroindustrial development in particular regions, then those crops that are well proven (e.g., sugarcane) should be prioritized for expansion before those crops with which there is limited experience (e.g., jatropha, sweet sorghum). These alternative crops should only be prioritized once their potential is proven. This suggests that significant research and development must be undertaken before large-scale implementation of unproven feedstocks is contemplated (Section 6).

It should be mentioned here that economic viability is only one of the several considerations when designing biofuel policies, albeit an important one. Social and environmental sustainability criteria are also important and need to be increasingly considered (Recommendation 11).

Recommendation 6: Minimize the potential for food-fuel competition

All current biofuel feedstocks in Africa can compete either directly or indirectly with food production (Section 3.2.1.2, 4.2.1.2, Table 12) and as a result might affect household, local and national food security (Section 3.4.2, 4.4.2, Table 20). Even for non-food/feed crops, such as jatropha, high yields are only possible through the use of fertilizers, sufficient amounts of water and good soil. As a result it is unlikely that viable seed yields can be obtained on marginal lands. Even in situations where marginal land is used, this will most likely involve the displacement of pastoral activities and access to woodland products (Section 3.3, 4.3).

It is fair to say that most of Africa's food security problems predate biofuels and is a result of factors not necessarily linked to biofuels. At the same time, it is important to ensure that biofuels production will not affect local and national food security in Africa which hosts some of the highest incidences of malnutrition globally.

Towards this end, biofuel policies can include provisions for prohibiting feedstock production in prime agricultural land or in areas with high prevalence of food insecurity. Incentives should be given to farmers in such areas not necessarily to drop food production in favour of feedstock production or cede their land to large-scale biofuel projects. This might prove to be a safety net when the achieved feedstock yields are low or uneconomic, as often is the case with jatropha (Section 5).

Also there should be an attempt to increase agricultural productivity both in the food and the biofuel sector. Foreign exchange savings and earnings from biofuel trade could potentially contribute funding to achieve this, e.g. through assisting the purchase of agricultural inputs (fertilizers, tractors) or the development of more tolerant and high yielding crop varieties (Section 6).

In any case the nexus of food, energy and rural development is a particularly tough puzzle to solve (Stromberg and Gasparatos, 2012). As a result any policies that are put in place need not only be based on the best available evidence, but need to be reflexive in order to tackle unforeseen biofuel-related decreases on food production that might threaten local and national food security.

Recommendation 7: Create appropriate land tenure mechanisms

In almost every African country a large proportion of rural land is under some form of customary tenure, with communal use of the rangelands and forests being particularly common. A large proportion of the land identified as suitable for biofuel expansion falls under such tenure regimes (Section 3.4.5, 4.4.5).

We have discussed cases of land tenure problems arising in different parts of Africa during the development of jatropha projects (Section 3.4.1, 3.4.5). Attention on land tenure issues should also be paid during sugarcane expansion in the continent. Evidence from Brazil has shown that sugarcane ethanol production benefits from economies of scale. Distilleries built within large monocultures are the dominant mode of production (Section 4.4.1). This has historically led to the concentration of land to a few very powerful actors (Section 4.4.5). Several authors have identified this loss of land tenure and the subsequent concentration of power to a few powerful actors as the main starting point of the negative social issues associated with sugarcane ethanol in Brazil (Abramovay, 2008; Lehtonen, 2012). If sugarcane ethanol is to be promoted in Africa, then policies that can safeguard the land tenure rights of smallholders and local communities need to be established.

Land tenure policy regimes should be amended so as to allow the individuals of local communities that cede their land to large biofuel plantations to maintain their tenure when large-scale biofuel projects are established, or to regain their tenure if such projects fail (e.g. Section 3.4.1). Lease agreements could be made directly with those currently having tenure to the land, (rather than with the state). Mechanisms such as village land trusts or equity-based joint ventures may be appropriate for this purpose (Sulle and Nelson, 2009). Also regulating the maximum size of core estates in large-scale biofuel projects and demanding a part of their production come from outgrowers, can also ensure greater equity of ownership (von Maltitz and Stafford, 2011).

In any case, it is important that tenure arrangements should, to the extent possible, disincentivize feedstock production in sensitive ecosystem (Section 3.3, 4.3) and avoid the destruction of traditional natural resource management systems (Section 3.2.3, 4.2.3).

Recommendation 8: Prevent speculative behaviour by biofuel ventures

There have been several cases of biofuel projects (jatropha in particular) that have failed to meet their initial production targets, thus closing down (Section 3.4.1). In some cases this might have been the result of predatory and speculative behaviour by firms, which have nevertheless affected negatively the livelihoods of local populations. Such speculative behaviour by investors can also be observed and to smallholder projects, leaving farmers holding the majority of the risk.

Policies should ensure that biofuel ventures in Africa (particularly foreign-led) must concretely exhibit their viability potential before given the green light to proceed. Economic viability is a key factor affecting the sustainability of biofuel projects and as a result it is reflected byone of the certification criteria of the Roundtable on Sustainable Biofuels (Principle 2). This means that African governments need to strike a fine balance between providing incentives for attracting foreign investment in the agricultural sector and at the same time ensure that these investments will fulfill their promised potential.

The use of independent audit mechanisms to ensure the viability of the proposed business plans based on best available evidence and a clear compensation regime in the event that biofuel projects fail, will be crucial. Strong enforcement and monitoring of the above can go a long way towards curbing speculative behaviour by biofuel companies. Reducing the exposure of poor households to biofuel project failures will limit risks associated with the loss of wages and revenues.

Recommendation 9: Promote regional biofuel markets

Biofuel policies in Africa are designed at the national level (Section 1.2.2). However there are signs that Africa is moving towards greater economic integration. Supranational institutions such as the SADC, the East African Community, the Common Market for Eastern and Southern Africa and the African Union are only some examples of institutions that aim to promote cooperation between African countries.

While some African countries have good potential to produce certain biofuel feedstocks (e.g. Mozambique, Zambia) (Section 3.1, 4.1), they currently lack mature markets that can boost biofuel production and use within their national borders (Section 3.4.1, 4.4.1). On the other hand countries that can benefit from biofuel use either lack appropriate agricultural conditions or are unable to pursue the production of certain feedstocks. One such example is South Africa that has put biofuel mandates in place, but exhibits relatively low sugarcane productivity compared to neighboring countries (Table 5) or has banned jatropha production due to concerns over its invasive behaviour (Section 3.3). Such countries could potentially benefit from the import of biofuel, feedstock or other biofuel co-products.

Additionally, regional integration of biofuel markets could make vehicle fleet modernization (e.g. vehicles adapted to run on higher ethanol blends) technologically and economically feasible. Such fleet modernization could be more challenging to be achieved by small and poor biofuel-producing countries. For example, South Africa has a huge vehicle fleet but a very modest blending target (E2), whilst many of its neighboring countries such as Mozambique, Zambia and Angola have small vehicle fleets but could easily exceed their ethanol production potential. As already mentioned vehicle fleet modernization can be a way to improve urban air quality (Section 4.2.2.2).

Policies that can facilitate regional biofuel/feedstock trade could be a possible way to achieve the viability of biofuel markets in the region (Recommendation 3) while at the same accelerating vehicle fleet modernization. This can offer significant health and environmental co-benefits (Section 3.2.2.2, 3.4.4, 4.2.2.2, 4.4.4).

Recommendation 10: Promote bilateral cooperation

Brazil is by far the largest producer of sugarcane ethanol (Section 4.1). At the same time Brazil is actively trying to make ethanol a global agricultural commodity that will allow Brazilian sugarcane ethanol to enter the US market (Section 1.2.1). For this reason Brazil through its ethanol diplomacy is aiming to boost sugarcane ethanol production in other parts of the world, Africa included.

A stronger cooperation between African and the Brazilian governments, through the transfer of sugarcane ethanol technology and know-how, can provide a golden opportunity for African countries to leapfrog in their sugarcane ethanol production capabilities.

Recommendation 11: Include environmental and social concerns in biofuel policies

This report has shown that biofuel landscapes can have a wide range of environmental and socioeconomic impacts. However with the exception of a few key impacts, environmental and social criteria are absent from biofuel policies. This is a common occurrence in developed and developing countries alike (Section 1.4).

Environmental and social criteria should be articulated in biofuel policies across Africa. Furthermore, these policies should include provisions for the strong implementation of these social and environmental criteria. Such provisions can be supported by the mandatory use of strategic environmental assessment, environmental impact assessment and social impact assessment particularly when large-scale biofuel projects are put in place. A key provision should be requiring such large-scale projects to protect areas of high conservation importance within their estates. Requiring the certification of such projects through independent third party certification schemes such as the round table on sustainable biofuels (RSB), or the better sugar initiative, could assist towards the development of sustainable biofuels in Africa.

Recommendation 12: Provide incentives to reduce harmful environmental practices

There should be efforts to ban harmful production practices such as agricultural burning (Section 4.2.2.2) and the use of dangerous agrochemicals (Sections 4.2.1.3). Also there should be provisions that prohibit the conversion of sensitive ecosystems, biodiversity-rich areas and ecosystems that provide significant ecosystem services to local populations (e.g. Section 4.3). Incentives to large-producers to adopt biodiversity-friendly production pratices can further assist the reduction of the environmental impact of feedstock production beyond protected areas.

Recommendation 13: Consider tradeoffs and unintended consequences along the full life cycle of biofuel chains

This report has extensively discussed that there can be radically different impacts (in type and magnitude) across the different stages of a biofuel's life cycle (Tables 11-22).

Policies that govern the viability and sustainability of biofuel projects, must be able to consider environmental and socioeconomic tradeoffs along the full life cycle of biofuel chains. Putting such provisions in place will make clearer the trade-offs associated with biofuel production and use to decision makers. Even though it might be possible to achieve win-win solutions through biofuel systems, policy makers should be aware (and have the capacity to be informed) that this might not always be the case. A life cycle mentality in biofuel policies can provide the basis for transparent and evidence-based decision-making.

Biofuel policies must also be able to consider the multiple uncertainties associated with biofuel production. Policies should be reflexive and able to deal with unintended consequences that may be an outcome of even the best of policy intentions. Enforcing strong monitoring mechanisms during the implementation of current biofuel policies/projects can go a long way towards capturing the occurrence of such secondary impacts and unintended consequences (both positive and negative).

8. Conclusions

Biofuel production has increased significantly across Africa during the last few years. Export to international markets, rural development and energy security seem to be significant drivers of this expansion in several parts of the continent.

Jatropha (for biodiesel) and sugarcane (for bioethanol) are the two feedstocks that have attracted the most attention in Africa with feedstock production in large-scale plantations (sometimes linked to outgrowers) and smallholder schemes being the two dominant modes of production. There are also reports of small-scale biofuel projects where biofuel (usually straight jatropha oil) is produced and used locally for rural electrification and power generation purposes.

New markets for biofuels and their co-products could potentially boost agricultural development, rural job creation and rural incomes and as such contribute to poverty alleviation in Africa. However, biofuel production and use can have significant environmental and socioeconomic impacts at the local, national and international level. Even though biofuels' negative impacts have attracted so far most of the attention, there are examples of biofuel practices contributing positively to human well-being and poverty alleviation.

On several occasions, the discussion about biofuel sustainability is dominated by a relatively small number of such impacts; most notably food security, economic feasibility and GHG emissions. In this report we discuss a much wider array of impacts, as we strongly believe that a piecemeal discussion of biofuel impacts can be easily misunderstood, manipulated and used to support narrow interests. A major challenge for obtaining a comprehensive picture of biofuel tradeoffs is the fact that the biofuel literature is multidisciplinary and rapidly expanding. To make matters more complicated there does not exist a consistent way to report the findings about biofuels' environmental and socioeconomic impacts.

This report employs the ecosystem services framework developed during the Millennium Ecosystem Assessment (MA), as a means of synthesizing the available evidence about biofuel impacts and identifying the main trade-offs associated with biofuels in Africa

Our in depth review of the academic literature found that biofuel landscapes in Africa can provide, displace, divert and degrade a large number of provisioning, regulating and potentially cultural ecosystem services. The ecosystem services that have been mostly associated with biofuel landscapes in Africa include:

- fuel feedstock, food, feed, fibre, water (provisioning services)
- climate regulation, air quality regulation, erosion regulation (regulating services)

The ecosystem services provided, displaced, diverted and degraded by biofuels can link into human well-being in multiple ways. In most cases there are significant human well-being trade-offs. However these trade-offs can depend on a number of factors such as the feedstock, the mode of production and the environmental and socioeconomic context of biofuel production and use.

Some of these trade-offs are inevitable, but in many cases part of the negative impact can be mitigated through careful planning. For example, while there is a high likelihood of direct and indirect competition between biofuel and food production, the impacts on food security are not always necessarily negative. Both positive and negative impacts on food security have been predicted and in some cases observed. In a similar manner, biodiversity impacts due to biofuel-induced direct and/or indirect land use change will depend on the type of land being converted into biofuel landscapes. Conversion of undisturbed ecosystems will most likely have high negative impacts on biodiversity, which is the basis of ecosystem services.

Jatropha remains an unproven technology and to date successes have been few. Many of the claims associated with jatropha such as its suitability for marginal areas or the ability to obtain economic yields with low agricultural inputs (e.g. fertilizer, water) have not been proven. Furthermore, much of the currently available data on jatropha is contradictory. For example, information based on projections tends to differ substantially from actual project experience. In any case, the mode of production seems to be making a big difference, though successes and failures have been reported from both large-scale projects and smallholder schemes. In general however, it seems that small-scale projects, especially those that make use of locally produced biofuel, can offer the highest rural development and poverty alleviation benefits. In any case, we have to stress that at present jatropha remains a high-risk crop with relatively modest energetic and economic returns.

Sugarcane ethanol production is a well-proven technology. Several African countries have experience in the sugar sector and have had successes blending amount of ethanol into transport fuel. However with the exception of Brazil, no other country has currently managed to displace large amounts of transport fuel with sugarcane ethanol. Plans to expand ethanol production across the continent can built on this significant experience within Africa and beyond. However it must be kept in mind that the socioeconomic conditions of sugarcane ethanol production in Brazil are quite different than those encountered in Africa. In Brazil almost all of the sugarcane is produced in large plantations with smallholders having practically disappeared. As a result significant power differential have emerged between the agro-industrial oligarchies and the plantations workers. The situation in Africa is somewhat different, not the least due to, the large number of smallholders involved in the sugarcane sector and the informal land tenure institutions. This means that caution should be paid when designing policies for sugarcane expansion in Africa if undesirable social and environmental side effects are to be avoided.

We conclude this report by drawing attention to the significant research gaps at the interface of biofuels, ecosystem services and human well-being. The incomplete and piecemeal understanding of biofuel impacts in Africa, combined with the low yields currently achieved (mainly from jatropha projects), are at this point the most important barriers for the development of policies that can ensure the viability and sustainability of future biofuel expansion in Africa. Based on the existing knowledge reviewed in depth in this report we offer the following list of policy recommendations.

Recommendation 1:	Adopt biofuel policies that reflect national realities and are compatible with wider policy objectives
Recommendation 2:	Promote rural development through support to small feedstock producers
Recommendation 3:	Develop viable biofuel and biofuel co-product markets and promote environmentally sound biofuel technologies

Recommendation 4: Coordinate institutional support and develop an innovation system for sustainable biofuel production

Recommendation 5: Base feedstock choices on proper agronomic knowledge

Recommendation 6: Minimize the potential for food-fuel competition

Recommendation 7: reate appropriate land tenure mechanisms

Recommendation 8: Prevent speculative behaviour by biofuel ventures

Recommendation 9: Promote regional biofuel markets

Recommendation 10: Promote bilateral cooperation

Recommendation 11: Include environmental and social concerns in biofuel policies

Recommendation 12: Provide incentives to reduce harmful environmental practices

Recommendation 13: Consider tradeoffs and unintended consequences along the full life cycle of biofuel chains

As a final word, we cannot stress enough how important it is for policymakers to understand the national and local context within which biofuel production and use is going to take place. Understanding this context and the competing interests and tradeoffs of biofuel production and use can go a long way toward designing effective biofuel policies.

Appendix

Area	South Africa, Zambia
Source	(Borman et al., 2012), Journal paper
Production/ consumption mode	Smallholders and large-scale jatropha production (for biodiesel production for transport purposes)
Methodology	Modelling based on yield to determine maximum wage that can be sustainably covered by biofuel production
Type of ecosystem service or biodiversity component affected	Fuel (provisioning service) Food (provisioning service) Fertilizer (provisioning service)
Trend	Fuel: increasing (nationally but not locally) Food: possibly decreasing (locally and nationally) Soil fertility: possible fertility gains
Mechanism	Feedstock provision from large biofuel plantations- (displacement of other services, incl. food, not considered) Feedstock production by smallholders potentially replaces food crops (displacement of food onsidered) Jatropha seedcake can be used as fertilizser (could be used locally or sold to a different region)
Scale of impact	Modelled based on local impacts
Link to human well-being or poverty alleviation	Yes – model uses either wage equivalents on poverty lines as baselines
Mechanism	Wages from large-scale plantations are able to meet minimum wage requirements in Zambia (but not in South Africa); For smallholders (Zambia) a relatively low yield of jatropha will give higher cash returns than displaced staple crops (this is only true for surplus food that is sold, and not necessarily for food used for home consumption); Model suggests possible positive poverty alleviation benefits with yields above 1 t/ha for Zambia. Benefits are negative in South Africa due to high wages.
Scale of human well-being or poverty alleviation impact	Local
Original land use	Agricultural land (maize): for smallholders NA: for large-scale production
Yields	Assumed. Model used jatropha yield values between 0 and 5 t/ha
Land rights/tenure	Communal area in Zambia: individuals have access to 10 ha per household
Comment	NA

Area	South Africa
Source	(Everson et al., 2012), Journal article
Production/ consumption mode	Experimental station (Assumed for transportation fuel)
Methodology	Field trials on research station
Type of ecosystem service or biodiversity component affected	Fuel (provisioning) Fodder (provisioning) Water (provisioning) Biodiversity
Trend	Fuel: low increase Water: neutral impacts Fodder: decrease Biodiversity: potential decrease
Mechanism	Fuel: Low expected feedstock production due to low yields Water: Jatropha evapotranspitation rates are similar to that of natural vegetation Fodder: Competition between grass and jatropha. Partial or total clearing of grass was recommended to enhance jatropha seed yield Biodiversity: Though not explicitly investigated in this study, it can be inferred that keeping the area between trees clear of natural grass vegetation is good for seed production. Grass clearing might have possible negative impact on biodiversity
Scale of impact	Local
Link to human well-being or poverty alleviation	Not explicitly linked – (potentially poor)
Mechanism	Jatropha yields too low for it to be a viable feedstock production option. Seed collection and de-husking is too labour intensive to be profitable, especially at the low yields observed. Though mixed jatropha-grazing systems are possible, the base of trees must be kept clear of grass and weeds to increase yield. This reduces overall grazing potential.
Scale of human well-being or poverty alleviation impact	Local
Original land use	NA
Yields	78–348 kg/ha (for 4 year trees) Highest yields were achieved with low grass competition.
Land rights/tenure	NA
Comment	NA

Area	Malawi
Source	(Dyer et al., 2010), Journal article
Production/ consumption mode	Small-scale projects (mainly for household use, surplus seeds sold presumably for national fuel needs)
Methodology	Household interviews, focus groups
Type of ecosystem service or biodiversity component affected	Fuel (provisioning) Food (provisioning) Soap (provisioning)
Trend	Fuel: increase Food: not affected Soap: increase
Mechanism	Jatropha oil is used to provide fuel and to make soap. These products can be used to replace expensive purchased items such as engine fuel, soap and paraffin
Scale of impact	Household level
Link to human well-being or poverty alleviation	Yes - positive livelihood impacts
Mechanism	Largest benefits are obtained from local use of jatropha oil for soap production and/or paraffin replacement (locally-produced renewable fuel replacing expensive purchases) Only surplus jatropha seeds are sold for biodiesel production. Food production not affected as the farmers continued to grow maize
Scale of human well-being or poverty alleviation impact	Household
Original land use	Mostly existing small scale farms
Yields	NA, but suggested that plantations achieve lower yields than expected
Land rights/tenure	Individual farms
Comment	The authors suggest that household level use will be a better option than production for commercial sale. Suggests that crop diversification increases household resilience.

Area	Mozambique
Source	(Schut et al., 2011), Journal paper
Production/ consumption mode	Small-scale projects (production for household fuel purposes and soap)
Methodology	Simple scenario analysis based on a very limited number of household interviews
Type of ecosystem service or biodiversity component affected	Fuel (provisioning service) Food (provisioning service) Soap (provisioning service Fertilizer (provisioning service)
Trend	Fuel: increase Food: unchanged Soap: increase Fertilizer: increase
Mechanism	Jatropha oil is used to provide fuel and to make soap. These products can be used to replace expensive purchased items such as engine fuel, soap and paraffin. Jatropha seedcake can be used as a fertilizer. Farmers intercropped jatropha with other food crops to reduce displacement of food production.
Scale of impact	Local
Link to human well-being or poverty alleviation	Yes – link established empirically
Mechanism	Use jatropha to replace expensive purchases such as fuel and soap. Increased local fuel availability Crop productivity improvement from seedcake fertilizer. However, the extent to which these uses are actually being made is not given. Profit from this local use is 2–4 times higher than if seeds were sold to the biofuel market for biodiesel production. One of the reasons was because jatropha growing household found no organized market for jatropha seeds, so did not know what to do with the seeds.
Scale of human well-being or poverty alleviation impact	Local (household)
Original land use	Smallholder farms (intercropping with pigeon peas)
Yields	Assumes yield of 1,250 kg/ha but not based on project experience
Land rights/tenure	Smallholders farmers - on customary land
Comment	Relatively realistic yields. Although some plants were doing well, many of the Jatropha in the area rotted during a wet period. States that very few small-scale jatropha growers are to be found in Mozambique .

Area	Ghana, Zambia
Source	(Achten and Verchot, 2011), Journal paper
Production/ consumption mode	Ghana: Large plantation Zambia: Outgrowers connected to a private company
Methodology	Carbon debts were followed using the methodology by Fargione et al. (2008)
Type of ecosystem service or biodiversity component affected	Climate regulation (regulating)
Trend	Climate regulation: decrease
Mechanism	Jatropha planting was responsible for direct and indirect LUCC. This resulted in significant carbon debts and high repaying times. Ghana: carbon debts of 243.2-258.2 Mg CO_2, requiring 46-188 years to be repaid. Zambia: carbon debts of 39–59 Mg CO_2, requiring 71-135 years to be repaid
Scale of impact	Global
Link to human well-being or poverty alleviation	Yes - Link not empirically established
Mechanism	Assumptions were made that "*in addition to the by-products any LUC also results in the production of other crops to which part of the carbon change must be allocated. To estimate this allocation we assume that (1) Jatropha is expected to offset decrease income of the food crop, (2) increasing competition makes intercropping economically unviable from year 4, and (3) the food-crop will be 100% in the first year, 50% in the second year, and 25% in the third year due to increasing competition with Jatropha*"
Scale of human well-being or poverty alleviation impact	Local
Original land use	Ghana: 46% mix of open/closed woodland, 23% permanent crops (10% yam, 13% other crops), 31% fallow land (naturally regenerative woodland) Zambia: 24% mature Miombo woodland, 61% permanent cropland (annuals), 15% fallow land
Yields	Collected from the literature
Land rights/tenure	NA
Comment	The study rests on significant assumptions regarding LUCC scale and Jatropha yields (use of 3 scenarios)

References

ABN, 2007, *Agrofuels in Africa; The Impacts on Land, Food and Forests.* Nairobi: African Biodiversity Network.

Abramovay, R., 2008. A *political-cultural approach to the biofuels market in Brazil*. Sao Paulo: University of Sao Paulo.

Achten, W.M.J. and Verchot, L.V., 2011. Implications of biodiesel-induced land-use changes for CO2 emissions: Case studies in Tropical America, Africa and Southeast Asia. *Ecology and Society*. [e-journal] 16(4): 14. Available at <http://dx.doi.org/10.5751/ES-04403-160414> [Accessed 12 September 2012].

Achten, W.M.J., Maes, W.H., Aerts, R., Verchot, L., Trabucco, A., Mathijs, E., Singh, V.P. and Muys, B., 2010a. Jatropha: From global hype to local opportunity. *Journal of Arid Environments*, 74(1), pp.164–165.

Achten, W.M.J., Almeida, J., Fobelets, V., Bolle, E., Mathijs, E., Singh, V.P., Tewari, D.N., Verchot, L.V. and Muys, B., 2010b. Life cycle assessment of Jatropha biodiesel as transportation fuel in rural India. *Applied Energy*, 87(12), pp.3652–3660.

Achten, W.M.J., Maes, W.H., Reubens, B., Mathijs, E., Singh, V.P., Verchot, L. and Muys, B., 2010c. Biomass production and allocation in Jatropha curcas L. seedlings under different levels of drought stress. *Biomass and Bioenergy*, 34(5), pp.667–676.

Achten, W.M.J., Verchot, L., Franken, Y.J., Mathijs, E., Singh, V.P., Aerts, R. and Muys, B., 2008. Jatropha bio-diesel production and use. *Biomass and Bioenergy*, 32(12), pp.1063–1084.

Achten, W.M.J., Mathijs, E., Verchot, L., Singh, V.P., Aerts,R. and Muys B., 2007. Perspective Jatropha biodiesel fueling sustainability? *Biofuels, Bioproducts and Biorefining*, 1(4), pp.283–291.

Agoramoorthy, G., Hsu, M.J., Chaudhary, S. and Shieh, P., 2009. Can biofuel crops alleviate tribal poverty in India's drylands? *Applied Energy*, 86(Supplement 1), pp.S118–S124.

Almeida, J., Achten, W.M.J., Duarte, M.P., Mendes, B.M. and Muys, B.M., 2011. Benchmarking the environmental performance of the jatropha biodiesel system through a generic life cycle assessment. *Environmental Science and Technology*, 45(12), pp.5447–5453.

Almeida, W., 2009. Ethanol diplomacy: Brazil and U.S. in search of renewable energy. *Globalisation, Competitiveness, and Governability*, 3(3), pp.114–124.

Ariza-Montobbio, P. and Lele, S., 2010. Jatropha plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs, and latent conflict. *Ecological Economics*, 70(2), pp.189–195.

Ariza-Montobbio, P., Sharachchandra, L., Kallis, G. and Martinez-Alier, J., 2010. The political ecology of jatropha plantations for biodiesel in Tamil Nadu, India. *Journal of Peasant Studies*, 37(4), pp.875–897.

Arndt,C., Benfica, R. and Thurlow, J., 2011. Gender implications of biofuel expansion in Africa: The case of Mozambique. *World Development*, 39(9), pp.1649–1662.

Arndt, C., Benfica, R., Tarp, F., Thurlow, J. and Uaiene, R., 2010. Biofuels, poverty and growth: A computable general equilibrium analysis of Mozambique. *Environment and Development Economics*, 15(1), pp.81–105.

Arvidson, A., Noel, S., Axberg, G.N., Liwenga, E., Ngana, J. and Senzoto, R., 2009. *Initial Assessment of Socioeconomic and Environmental Risks and Opportunities of Large-scale Biofuels Production in the Rufiji District*. [pdf] Dar es Salaam: SEKAB Bioenergy. Available at: <http://www.tabef.or.tz/wp-content/uploads/2011/03/Risk-Assessment-of-SEKABscluster-approach-in-Rufiji-District-2805091.pdf> [Accessed 13 September 2012].

Bailis, R.E. and Baka, J.E., 2010. Greenhouse gas emissions and land use change from Jatropha curcas-based jet fuel in Brazil. *Environmental Science and Technology*, 44(22), pp.8684–8691.

Bailis, R. Ezzati, M. and Kammen, D.M., 2005. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. *Science*, 308(5718), pp.98–103

Basinger, M., Chen, J., Jeffrey-Coker, F., Rodriguez-Sanchez, F.S., Singer, T. and Modi, V., 2012. Jatropha adoption: a statistical observational study of factors influencing Malian farmers' decision to grow Jatropha. *Agroforestry Systems*, 84(1), pp.59–72.

Batidzirai, B. and Johnson, F.X., 2012. Energy security, agroindustrial development, and international trade: The case of sugarcane in Africa. In: A. Gasparatos and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp. 254–277.

Bergius, M., 2012. *Large scale agro investments for biofuel production in Tanzania: Impact on rural households*. Adger: Institute of Development Studies, University of Agder.

Blanchard, R., Richardson, D.M., O'Farrell, P.J. and von Maltitz, G.P., 2011. Biofuels and biodiversity in South Africa. *South African Journal of Science*, [e-journal] 107(5-6), <http://www.sajs.co.za/index.php/SAJS/article/view/186/658> [Accessed 12 September 2012]

Boddey, R.M., de B. Soares, L.H., Alves, B.J.R. and Urquiaga, S., 2008. Bioethanol production in Brazil. In: D. Pimentel, ed. 2008. *Biofuels, solar and wind as renewable energy systems: Benefits and risks*. New York: Springer, pp.321–356.

Boerstler, B., 2010. *The potential for the production of bioenergy for lighting and cooking using Jatropha (Jatropha curcas L. Euphorbiaceae) by small scale farmers on the Kenyan coast*. Ph.D. RWTH Aachen.

Borman, G.D., von Maltitz, G.P., Tiwari, S. and Scholes, M.C., 2012. Modelling the economic returns to labour for Jatropha cultivation in southern Africa and India at differential local fuel prices. *Biomass and Bioenergy*. [online] Available at: <http://dx.doi.org/10.1016/j.biombioe.2012.06.020> [Accessed 20 June 2012].

Borras Jr., S.M. and Franco, J.C., 2012. Global land grabbing and trajectories of agrarian change: A preliminary analysis. *Journal of Agrarian Change*, 12(1), pp.34–59.

BSR, 2010. *State of Global Ecosystem Services Policy Developments*. San Francisco:BSR.

Cancado, J.E.D., Saldiva, P.H.N., Pereira, L.A.A., Lara, L.B.L.S., Artaxo, P., Martinelli, L.A., Arbex, M.A., Zanobetti, A. and Braga, A.L.F., 2006. The impact of sugar cane–burning emissions on the respiratory system of children and elderly. *Environmental Health Perspectives*, 114(5), pp.725–729.

Carrington, D., Paul, J., Maurayi, T. and Sprenger R., 2011. *Sun Biofuels have left us in a helpless situation: They have taken our land*. [video online] Available at: <http://www.guardian.co.uk/environment/video/2011/nov/09/biofuel-tanzania-video> [Accessed 16 August 2012].

Castanho, A.D. and Artaxo, P., 2001. Wintertime and summertime Sao Paulo aerosol source apportionment study. *Atmospheric Environment*, 35(29), pp.4889–4902.

CBD, 2012. COP10 Decision X37: *Biofuels and biodiversity*. Montreal: Secretariat of the Convention on Biological Diversity [online] Available at <http://www.cbd.int/decision/cop/?id=12303> [Accessed 12 September 2012].

CETESB, 2012. *Average emission factors of new vehicles. Environmental Authority of Sao Paulo State*. Sao Paulo: CETESB [online] Available at: <http://www.cetesb.sp.gov.br/ar/emissao-veicular/39-tabela-7---fatores-m?dios-de-emiss?o-de-ve?culos-leves---novos-%281%29#> [Accessed 12 September 2012].

Cleveland, C.J., Hall, C.A.S. and Herendeen, R.A., 2006. Energy returns on ethanol production. *Science*, 312(5781), pp.1746–1746.

Cohen, J., 2011.*The Observer reveals how UK company Sun Biofuels has 'wrecked lives of Tanzanian villagers*. London: Action Aid [online] Available at: <http://www.actionaid.org.uk/100621/blog.html?article=3581> [Accessed 4 September 2012].

Cotula, L., Dyer, N. and Vermeulen, S., 2008. Fuelling exclusion? *The biofuels boom and poor people's access to land*. London and Rome: International Institute for Environment and Development and Food and Agriculture Organization of the United Nations.

Dale, V.H., Kline, K.L. Wiens, J. and Fargione, J., 2010. Biofuels: Implications for land use and biodiversity. *Biofuels and Sustainability Reports*. Washington DC: Ecological Society of America.

De La Torre Ugarte, D.G. 2006. Developing bioenergy: economic and social issues. In: P. Hazell and R.K. Pachauri, ed 2006. *Bioenergy and agriculture: promises and challenges*. Washington DC: International Food Policy Research Institute.

Diaz-Chavez, R., Mutimba, S., Watson, H., Rodriguez-Sanchez, S. and Nguer, M., 2010. *Mapping food and bioenergy in Africa*. Ghana: Forum for Agricultural Research in Africa.

Dipml, E., 2011. Part III: vegetable oil. In: M.Blunck, ed. 2011. *Small-scale electricity generation from biomass*. Bonn: GIZ-HERA.

Dyer, K.W. 2012. *From technology transfer to innovation systems: sustaining a Green Revolution in Africa*. Brighton: Future Agricultures Consortium.

Dyer, J.C., Stringer, A.J. and Dougill, A.J., 2010. Jatropha curcas: Sowing local seeds of success in Malawi?. *Journal of Environments*, 79, pp.107–110.

EC, 2009. Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources. Official Journal of the European Union L140, pp.16-62.

EcoEnergy, 2012. *EcoEnergy project FAQ*. [online] EcoEnergy. Available at: <http://www.ecoenergy.co.tz/faq/project-faq/> [Accessed 5 September 2012].

EIA, 2012. *Uganda. Energy Information Administration*, U.S. Department of Energy. [online] Available at: <http://www.eia.gov/countries/country-data.cfm?fips=UG#tpe> [Accessed 5 May 2012].

van Eijck, J., 2007. *Transition towards Jatropha Biofuels in Tanzania? An analysis with strategic niche management*. M.Sc. Eindhoven University of Technology.

van Eijck, J., Smeets, E., Romijn, H., Balkema, A. and Jongschaap, R., 2010. *Jatropha Assessment: Agronomy, socio-economic issues, and ecology*. Utrecht: NL Agency. Energia, 2009. *Biofuels for sustainable rural development and empowerment of women: Case studies from Africa and Asia*. Leusden: Energia.

Energia, 2009. *Biofuels for sustainable rural development and empowerment of women: Case Studies from Africa and Asia.* Leusden: Energia.

EPA, 2009. *EPA lifecycle analysis of greenhouse gas emissions from renewable fuels*. Ann Arbor: Environmental Protection Agency.

Everson, C.S., Mengistu, M.G. and Gush, M.B., 2012. A field assessment of the agronomic performance and water use of Jatropha curcas in South Africa. *Biomass and Bioenergy*. [in press] Available at: <http://dx.doi.org/10.1016/j.biombioe.2012.03.013> [Accessed 12 September 2012].

FAO, 2012. *FAOSTAT databases*. Rome: Food and Agriculture Organization [online] Available at <http://faostat.fao.org/> [Accessed 30 July 2012].

FAO, 2010. *Jatropha: A Smallholder Bioenergy Crop*. Rome: Food and Agriculture Organization.

FAO, 2009. S*mall-scale bioenergy initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa*. Rome: Food and Agriculture Organization.

FAO, 2008. *From Subsistence farming to sugar-cane monoculture: impacts on agrobiodiversity, local knowledge, and food security*. Rome: Food and Agriculture Organization.

FAO, 2004. *Fertilizer use by crop in Brazil*. Rome: Food and Agriculture Organization.

Fargione, J., Hill, J., Tilman, D., Polasky, S. and Hawthrone, P., 2008. Land clearing and the biofuel carbon debt. *Science*, 319(5867), pp.1235–1238.

Field, C.B., Campbell, J.E. and Lobell, D.B., 2008. Biomass energy: the scale of the potential resource. *Trends in Ecology and Evolution*, 23(2), pp.65–72.

Filoso, S., Martinelli, L.A., Williams, M.R., Lara, L.B., Krusche, A., Ballester, M.V., Victoria, R.L. and Camargo, P.B., 2003. Land use and nitrogen export in the Piracicaba River basin, southeast Brazil. *Biogeochemistry*, 65(3), pp.275–294.

Fischer, G., Hizsnyik, E., Prielder, S., Shah, M. and van Velthuizen, H., 2009. *Biofuels and food security*. Vienna: International Institute for Applied Systems Analysis.

Fisher, B., Turner, R.K. and Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics, 68(3), pp.643–653.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Bruhl, C.A., Donald, P.F. and Phalan, B., 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolultion*, 23(10), pp.538–545.

FoE, 2011. *Jatropha: money doesn't grow on trees ten reasons why jatropha is neither a profitable nor sustainable investment*. London: Friends of the Earth.

Franco, J., Levidow, L., Fig, D., Goldfarb, L., Honicke, M. and Mendonca, M.L., 2010. Assumptions in the European Union biofuels policy: Frictions with experiences in Germany, Brazil and Mozambique. *Journal of Peasant Studies*, 37(4), pp.611–698.

Franke, B., Gärtner, S., Köppen, S. and Reinhardt, G., 2010. *Bioenergy environmental impact analysis (BIAS) of ethanol production from sugar cane in Tanzania case study: SEKAB/Bagamoyo*. Rome: Food and Agriculture Organization.

Furtado, A.T., Scandiffio, M.I.G. and Cortez, L.A.B., 2011. The Brazilian sugarcane innovation system. *Energy Policy*, 39(1), pp.156–166.

Garcia, C.A., Fuentes, A., Hennecke, A., Riegelhaupt, E., Manzini, F. and Masera, O., 2011. Life- cycle greenhouse gas emissions and energy balances of sugarcane ethanol production in Mexico. *Applied Energy*, 88(6), pp.2088–2097.

Gasparatos, A. and Scolobig, A., 2012. Choosing the most appropriate sustainability assessment tool. *Ecological Economics*, 80, pp.1–7.

Gasparatos, A. and Stromberg, P., eds., 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press.

Gasparatos, A., Borzoni, M. and Abramovay, R., 2012a. The Brazilian bioethanol and biodiesel programmes: drivers, policies and impacts. In: A. Gasparatos, and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.111–143.

Gasparatos, A., Lehtonen, M. and Stromberg, P., 2012b. Do we really need a consistent way to synthesise evidence about biofuel tradeoffs? *Biomass and Bioenergy*, [online] Available at: <http:// 10.1016/j.biombioe.2012.09.052 > [Accessed 12 September 2012].

Gasparatos, A., Stromberg, P. and Takeuchi, K., 2011. Biofuels, ecosystem services and human wellbeing: Putting biofuels in the ecosystem services narrative. Agriculture, *Ecosystems and Environment*, 142(3-4), pp.111–128.

Gerbens-Leenes, W.P., Hoekstra, A.Y. and van der Meer, T.H., 2012. Water for bioenergy: A global analysis. In: A. Gasparatos and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.69–89.

Gerbens-Leenes, P.W., Hoekstra, A.Y. and van der Meer, T., 2009. The water footprint of bioenergy. *PNAS* 106(25), pp.10219–10223.

German, L., Schoneveld, G.C. and Gumbo, D. 2011a. The local social and environmental impacts of smallholder-based biofuel investments in Zambia. *Ecology and Society*. [e-journal] 16(4): 12. <http://dx.doi.org/10.5751/ES-04280-160412> [Accessed 12 September 2012]

German, L., Schoneveld, G.C. and Pacheco, P., 2011b. The social and environmental impacts of biofuel feedstock cultivation: evidence from multi-site research in the forest frontier. *Ecology and Society*. [e-journal] 16(3): 24 <http://dx.doi.org/10.5751/ES-04309-160324> [Accessed 12 September 2012]

GEXSI. 2008. Global *Market Study on Jatropha. Final Report*. London/Berlin: Global Exchange for Social Investment.

Gibbs, H.K., Johnston, M., Foley, J.A., Holloway, T., Monfreda, C., Ramankutty, N. and Zaks, D., 2008. Carbon payback times for crop-based biofuel expansion in the tropics: The effects of changing yield and technology. *Environmental Research Letters*, 3(3), pp.1–10.

Gibbs Russell, G.E., 1986. Significance of different centres of diversity in sub-families of Poaceae in southern Africa. *Palaeoecology of Africa*, 17, pp.183–191.

Gilbert, N., 2011. Local benefits: The seeds of an economy. *Nature*, 474(7352), pp.S18–S19.

Gmunder, S.M., Zah, R., Bhatacharjee, S., Classen, M., Mukherjee, P. and Widmer, R., 2010. Life cycle assessment of village electrification based on straight Jatropha oil in Chhattisgarh, India. *Biomass and Bioenergy*, 34(3), pp.347–355.

Goel, G., Makkar, P.S., Francies, G. and Becker, K., 2007. Phorbol esters: Structure, biological activity, and toxicity in animals. *International Journal of Toxicology*, 26(4), pp.279–288.

Goldemberg, J., 2008. The Brazilian biofuels industry. *Biotechnology for Biofuels*. [e-journal] 1:6 Available at: <http:// dx.doi.org/10.1186/1754-6834-1-6> [Accessed 12 September 2012].

Gomez-Baggethun, E., de Groot, R., Lomas, P.L., Montes, C., 2010. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics*, 69(6), pp.1209–1218.

Goncalves, J.S., Souza, S.A.M. and Ghobril, C.N., 2007. *Agropecuaria paulista: especializac a o regional and mudancas na composicao de culturas de 1969–1971 a 2002–2006*. Sao Paulo: Instituto de Economia Agrıcola.

Gressel, J., 2007. Transgenics are imperative for biofuels crops. *Plant Science*, 174(3), pp.246–263.

Grimsby, L.K., Bernt Aune, J. and Johnsen, F.H., 2012. Human energy requirements in Jatropha oil production for rural electrification in Tanzania. *Energy for Sustainable Development*, 16(3), pp.297–302.

Groom, M.J., Gray, E.M. and Townsend, P.A., 2008. Biofuels and biodiversity: principles for creating better policies for biofuel production. *Conservation Biology*, 22(3), pp.602–609.

GTZ, 2009. Jatropha Reality Check: A field assessment of the agronomic and economic viability of Jatropha and other oilseed crops in Kenya. Bonn: German Technical Cooperation Agency.

GTZ, 2005. *Liquid biofuels for transportation in Tanzania, potential and implications for sustainable agriculture and energy in the 21st century*. Bonn: German Technical Cooperation Agency.

Guariguata, M.R., Masera, O.T., Johnson, F.X., von Maltitz G., Bird N., Tella, P. and Martínez-Bravo, R., 2011. *A review of environmental issues in the context of biofuel sustainability frameworks*. Bogor: Centre for International Forestry Research.

Gunkel, G., Kosmol, J., Sobral, M., Rohn, H., Montenegro, S. and Aureliano, J., 2007. Sugarcane industry as a source of water pollution: Case study on the situation in Ipojuca River, Pernambuco, Brazil. *Water, Air, and Soil Pollution*, 180(1-4), pp.261–269.

Gupta, R.B. and Demirbas, A., 2010. *Gasoline, diesel and ethanol biofuels from grasses and plants*. New York: Cambridge University Press.

Gush M.B., 2008. Measurement of water-use by Jatropha curcas l. using the heat-pulse velocity technique. *Water South America*. [e-journal] 34(5) Available through: South African Water Research Commission [Accessed 12 September 2012].

Habib-Mintz, N., 2010. Biofuel investment in Tanzania: Omissions in implementation. *Energy Policy*, 38(8), pp.3985–3997.

Hamoen, R., Beerens, P., Langelaan, B., Voordouw, T., van den Boogaart, S. and Sanders, J., 2011. *Jatropha curcas processing: an overview*. Wageningen: Wageningen UR Food & Biobased Research.

Haywood, L., von Maltitz, G., Setzkorn, K. and Ngepah, N., 2008. *Biofuel production in South Africa, Mozambique, Malawi and Zambia: A status quo analysis of the social, economic and biophysical elements of the biofuel industry in Southern Africa*. Pretoria: Council for Scientific and Industrial Research.

Heller, J., 1996. Physic nut - Jatropha curcas L. - *Promoting the conservation and use of underutilized and neglected crops*. Ph.D. Institute of Plant Genetic and Crop Plant Research.

Henning, R.K. (n.d.) *Jatropha curcas in Africa - an Evaluation*. [pdf] Weissenberg: Bagani. Available at: <http://www.underutilized-species.org/Documents/PUBLICATIONS/jatropha_curcas_africa.pdf> [Accessed 10 September 2012].

Henning, R.K., 2009. *The Jatropha system, an integrated approach of rural development*. Weissenberg: Bagani.

Henning, R., 2000. *The jatropha booklet*. A guide to the jatropha system and its dissemination in Zambia. Chma: GTZ-ASIP-Support-Project Southern Province.

Hill, J., Nelson, E., Tilman, D., Polasky, S. and Tiffany, D., 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. PNAS 103(30), pp.11206–11210.

Hirota, M., Suttajit, M., Suguri, H., Endo, Y., Shudo, K., Wongchai, V., Hecker, E. and Fujiki, H., 1988. A new tumor promoter from the seed oil of Jatropha curcas L., an intramolecular diester of 12- deoxy-16-hydroxyphorbol. Cancer Research, 48(20), pp.5800–5804.

Horiuchi, T., Fujiki, H., Hirota, M., Suttajit, M., Suganuma, M., Yoshioka, A., Wongchai, V., Hecker, E. and Sugimura, T., 1987. Presence of tumor promoters in the seed oil of Jatropha curcas L. from Thailand. *Japanese Journal of Cancer Research*, 78(3), pp.223–226.

Hou, J., Zhang, P., Yuan, X. and Zheng, Y., 2011. Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions. *Renewable and Sustainable Energy Reviews*, 15(9), pp.5081–5091.

Hunsberger, C., 2010. The politics of Jatropha-based biofuels in Kenya: convergence and divergence among NGOs, donors, government officials and farmers. *Journal of Peasant Studies*, 37(4), pp.939–962.

IEA, 2011. *Energy Balances of Non-OECD Countries*. Paris: International Energy Agency.

IEA, 2010. *Sustainable production of second-generation biofuels: Potential and perspectives in major economies and developing countries*. Paris: International Energy Agency.

IEA, 2005. *World Energy Outlook 2006*. Paris: International Energy Agency.

IEA, 2004. *Biofuels for transport: An international perspective*. Paris: International Energy Agency.

IPCC, 2007. Climate Change 2007: Mitigation of Climate Change. *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

IRIN, 2007. *Mozambique: no lift off for biofuels yet.* IRIN Humanitarian news and analysis [online] Available at http://www.irinnews.org/PrintReport.aspx?ReportId=75382 [Accessed 4 September 2012].

JatroREF, 2012. J*atroREF: des referentiels pour des filieres agrocarburantes durable en Afrique de l'Ouest*. [online] Available at: <http://jatroref.org/> [Accessed 22 June 2012].

de Jongh, J. and Nielsen, F., 2011. *Lessons Learned: Jatropha for local development*. Wageningen: FACT Foundation.

Jongschaap, R.E.E., Blesgraaf, R.A.R., Bogaard T.A., van Loo E.N. and Savenije, H.H.G., 2009. The water footprint of bioenergy from Jatropha curcas L. PNAS, 106(35), E92.

Jongschaap, R.E.E., Corré, W.J., Bindraban, P.S. and Brandenburg, W.A., 2007. *Claims and Facts on Jatropha curcas L*. Wageningen: Plant Research International.

Karavina, C., Zivenge, E., Mandumbu, R. and Parwada, C., 2011. Jatropha curcas production in Zimbabwe: Uses, challenges and the way Forward. *Modern Applied Science*, 5(2), pp.239–243.

Kenya Ministry of Energy, 2011. *Scaling-up renewable energy program (SREP)*. Nairobi: Kenya Ministry of Energy.

Khatiwada, D. and Silveira, S., 2009. Net energy balance of molasses based ethanol: The case of Nepal. *Renewable and Sustainable Energy Reviews*, 13(9), pp.2515–2524.

Kitabu, G., 2011. Land rights research and resources institute (hakiardhi) investigative report on biofuel investments. [pdf] Dar es Salaam: Let's talk land Tanzania. Available at: <http://letstalklandtanzania.com/s/download/reports/Investigative%20Report%20on%20Biofuel%20Investment%20in%20Kisarawe%20and%20Rufiji%20Districts-1.pdf> [Accessed 5 September 2012].

Knopfle, M., 2004. *A Study on Charcoal Supply in Kampala, Advisory Project*. Kampala: Uganda Ministry of Energy and Mineral Development Energy.

Koh, L.P., Levang, P. and Ghazoul, J., 2009. Designer landscapes for sustainable biofuels. *Trends in Ecology and Evolution*, 24(8), pp.431–438.

Koizumi, T., 2009. Impact of the Chinese bioethanol import on the world sugar markets: An econometric simulation approach. International Sugar Journal, 111(1323), pp.38–49.

Koizumi, T. and Ohga, K., 2009. Impact of the expansion of Brazilian FFV utilization and U.S. biofuel policy amendment on the world sugar and corn markets: An econometric simulation approach. *Japanese Journal of Rural Economy* 11, pp.9–32.

Kojima, M. and Johnson, T., 2005. *Potential for Biofuels for Transport in Developing Countries*. Washington DC: World Bank.

Krivanek, M., Pysek, P. and Jarosık, V., 2006. Planting history and propagule pressure as predictors of invasion by woody species in a temperate region. *Conservation Biology*, 20(5), 1487–1498.

Kumar, S., Singh, J., Nanoti, S.M. and Garg, M.O., 2012. A comprehensive life cycle assessment (LCA) of Jatropha biodiesel production in India. *Bioresource Technology*, 110, pp.723–729.

Kunen, E. and Chalmers, J., 2010. *Sustainable biofuel development policies, programs and practices in APEC economies*. Arlington: Winrock International.

Lapola, D.M., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Koelking, C. and Priess, J.A., 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. *PNAS* 107(8), pp.3388–3393.

Lara, L.L., Artaxo, P., Martinelli, L.A., Camargo, P.B., Victoria, R.L. and Ferraz, E.S.B., 2005. Properties of aerosols from sugar-cane burning emissions in southeastern Brazil. *Atmospheric Environment*, 39(26), pp.4627–4637.

Lara, L.L., Artaxo, P., Martinelli, L.A., Victoria, R.L., Camargo, P.B., Krusche, A., Ayers, G.P., Ferraz, E.S.B. and Ballester, M.V., 2001. Chemical composition of rainwater and anthropogenic influences in the Piracicaba River Basin, southeast Brazil. *Atmospheric Environment*, 35(29), pp.4937–4945.

Lehtonen, M., 2012. Power, social impacts and certification of ethanol fuel: View from the Northeast of Brazil. In: A. Gasparatos and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.144–170.

Lehtonen, M., 2010. *Status report on sugarcane agrochemicals management*. Oullins: Ethical Sugar.

Le Maitre, D.C., van Wilgen, B.W., Gelderblom, C.M., Bailey, C., Chapman, R.A. and Nel, J.A., 2002. Invasive alien trees and water resources in South Africa: Case studies of the costs and benefits of management. *Forest Ecology and Management*, 160(1-3), pp.143–159.

Lerner, A., Matupa, O., Mothlathledi, F., Stiles, G. and Brown, R. 2010. *SADC Biofuel State of Play*. Gabarone: Southern African Development Community.

Lin, J., Yan, F., Tang, L. and Chen, F., 2003. Antitumor Effects of Curcin from Seeds of Jatropha curcas. *Acta Pharmacologica Sinica*, 24(3), pp.241–246.

Luo, M.J., Yang, X.Y., Liu, W.X., Xu, Y., Huang, P. and Yan, F., 2006. Expression, Purification and Anti-Tumor Activity of Curcin. Acta Biochimica et *Biophysica Sinica*, 38(9), pp.663–668.

MA, 2005a. *Millennium Ecosystem Assessment: Current State and Trends Assessment*. Washington: Island Press.

MA, 2005b. *Millennium Ecosystem Assessment: Biodiversity Synthesis*. Washington DC: Island Press.

Macedo, I.C., Leal, M.R.L.V. and Da Silva, J.E.A.R., 2004. *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil*. Sao Paulo: Secretariat of the Environment of the State of Sao Paulo.

Maes, M.H., Achten, W.M.J., Reubens, B., Samson, R. and Muys, B., 2009a. Plant-water relationships and growth strategies of Jatropha curcas L. saplings under different levels of drought stress. *Journal of Arid Environments*, 73(10), pp.877–884.

Maes, W.H., Achten, W.M.J. and Muys, B., 2009b. Use of inadequate data and methodological errors lead to an overestimation of the water footprint of Jatropha curcas. *PNAS*, 106(35), p.E91.

Makutsa, P. 2010. *Land grab in Kenya: Implications for smallholder farmers.* Eastern Africa Farmers Federation, Nairobi.

von Maltitz, G.P. and Setzkorn, K., 2012. Potential impacts of biofuels on deforestation in Southern Africa. *Journal of Sustainable Forestry*, 31(1-2), pp.80–97.

von Maltitz, G.P., Sugrue, A., Gush, M.B., Everson, C., Borman, G.D. and Blanchard, R., 2012. Environmental and socioeconomic considerations for jatropha growing in southern Africa. In: A. Gasparatos and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.278–305.

von Maltitz, G. and Stafford, W., 2011. *Assessing opportunities and constraints for biofuel development in sub-Saharan Africa*. Bogor: Center for International Forestry Research.

von Maltitz, G.P., Nickless, A. and Blanchard, R., 2010. Maintaining biodiversity during biofuel development. In: J.M. Amezaga, G.P. von Maltitz and S.L. Boyes, ed. 2010. *Projects in developing countries: A framework for policy evaluation*. Newcastle upon Tyne: Newcastle University, pp. 81-118.

von Maltitz, G.P., Haywood, L., Mapako, M. and Brent, A., 2009. *Analysis of opportunities for biofuel production in sub-Saharan Africa*. Bogor: Center for International Forestry

Research.

Von Malititz, G.P. and Brent, A., 2008. Assessing the biofuel options for Southern Africa. In: CSIR (Council for Scientific and Industrial Research), *Science real and relevant: 2nd CSIR Biennial Conference*. Pretoria, South Africa 17–18 November 2008. Pretoria: CSIR.

Maltsoglou, I. and Khwaja, Y., 2010. Bioenergy and food security: *The BEFS analysis for Tanzania*. Rome: Food and Agriculture Organization.

Martin, T.G. and Catterall, C.P., 2001. Do fragmented coastal heathlands have habitat value to birds in eastern Australia? *Wildlife Research*, 28(1), pp.17–31.

Martinelli, L.A. and Filoso, S., 2008. Expansion of sugar cane ethanol production in Brazil: Environmental and social challenges. *Ecological Applications*, 18, pp.885–898.

Martinelli, L.A., Camargo, P.B., Lara, L.B.L.S., Victoria, R.L. and Artaxo, P., 2002. Stable carbon and nitrogen isotope composition of bulk aerosol particles in a C4 plant landscape of southeast Brazil. *Atmospheric Environment*, 36(2002), pp.2427–2432.

Matango, R., 2006. *Mtibwa outgrowers scheme: A model for small holder cane production in Tanzania*. Geneva: United Nations Conference on Trade and Development.

Matondi, P.B., Havnevik, K. and Beyene, A. eds., 2011. *Biofuels, Land Grabbing and Food Security in Africa*. London: Zed Books.

Menichetti, E. and Otto, M., 2009. Energy balance and greenhouse gas emissions of biofuels from a product life-cycle perspective. In: R.W. Howarth and S. Bringezu, eds 2009. *Biofuels: Environmental consequences and interactions with changing land use*. Ithaca: Cornell University, pp.81–109.

MEPU, 2010. *Energy sector overview*. Port Louis: Ministry of Energy and Public Utilities of Mauritius.

Michalopoulos, A., Landerweerd, L., van der Werf-Kulichova, Z., Puylaert, P.G.B. and Osseweijer, P., 2011. Contrasts and synergies in different biofuel reports. *Interface Focus*, 1, pp.248–254.

Mitchell, D., 2011. *Biofuels in Africa: Opportunities, prospects and challenges*. Washington DC: World Bank.

Mitchell, D., 2005. Sugar policies: An opportunity for change. In: A. Aksoy and J. Beghin, ed. 2005. *Global agricultural trade and developing countries*. Washington DC: World Bank, pp.141–160.

MME, 2011. *National energy balances*. Brasilia: Ministerio de Minas e Energia.

Mota, M., 2009. *Potential changes in Mozambican farming systems due to Jatropha introduction for biodiesel*. M.Sc. Wageningen University.

Mucina, L. and Rutherford, M.C., eds., 2006. *The vegetation of South Africa, Lesotho and Swaziland*. Pretoria: South African National Biodiversity Institute.

Mumias Sugar Company, 2009. *Corporate strategy*. [online] Available at: <http://www.

mumias-sugar.com/index.php?page=corporate-strategy> [Accessed 28 May 2009].

Nassar, A.M., Harfuch, L., Moreira, M.M.R., Bachion, L.C. and Antoniazzi, L.B., 2009. *Report to the U.S. Environmental Protection Agency regarding the proposed changes to the renewable fuel standard program: Impacts on land use and GHG emissions from a shock on Brazilian sugarcane ethanol exports to the United States using the Brazilian Land Use Model (BLUM)*. Sao Paulo: Institute for International Trade Negotiations (ICONE).

Ndong, R., Montrejaud-Vignoles, M., Saint Girones, O., Gabrielle, B., Pirot, R., Domergue, D. and Sablayrolles, C., 2009. Life cycle assessment of biofuels from Jatropha curcas in West Africa: A field study. *Global Change Biology Bioenergy*, 1(3), pp.197–210.

Nguyen, T.L.T., Gheewala, S.H. and Garivait, S., 2007. Full chain energy analysis of fuel ethanol from cassava in Thailand. *Environmental Science and Technology*, 41(11), pp.4135–4142.

Nhantumbo, I. and Salomao, A., 2010, *Biofuels, land access and rural livelihoods in Mozambique.* London: International Institute for Environment and Development

Nielsen, F., De Jongh, B. and de Jongh, J., 2011. *End report FACT pilot project "Jatropha oil for local development in Mozambique" 2007-2010*. Wageningen: FACT Foundation.

Novo, A., Jansen, K., Slingerland, M. and Giller, K., 2010. Biofuel, dairy production and beef in Brazil: Competing claims on land use in Sao Paulo state. *Journal of Peasant Studies*, 37(4), pp.769–792.

Nyberg, J., 2012. *Sugar-based ethanol: International market profile*. Rome: Food and Agriculture Organization.

Nygaard, I., 2010. Institutional options for rural energy access: Exploring the concept of the multifunctional platform in West Africa. *Energy Policy*, 38(2), pp.1192–1201.

O'Connor, T.G. and Bredenkamp, G.J., 1997. Grassland. In: R.M. Cowling, D.M. Richardson and S.M. Pierce, ed. 1997. *Vegetation of South Africa*. Cambridge: Cambridge University Press, pp.215–257.

Oakland Institute, 2011. *Understanding land investment deals in Africa*. Oakland: Oakland Institute.

de Oliveira, M.E.D., Vaughan, B.E. and Rykiel, E.J., 2005. Ethanol as fuel: Energy, carbon dioxide balances and ecological footprint. *Bioscience*, 55(7), pp.593–602.

Oliver, C., 2005. *Environmental impact of sugar production*. Cambridge: CABI.

Openshaw, K., 2000. A review of Jatropha curcas: An oil plant of unfulfilled promise. *Biomass and Bioenergy*, 19(1), pp.1–15.

Oppenheimer, C., Tsanev, V.I., Allen, A.G., McGonigle, A.J.S., Cardoso, A.A., Wiatr, A., Paterlini, W. and de Mello Dias, C., 2004. NO2 emissions from agricultural burning in Sao Paulo, Brazil. *Environmental Science and Technology*, 38(17), pp.4557–4561.

Ou, X., Zhang, X., Chang, S. and Guo, Q., 2009. Energy consumption and GHG emissions of six biofuel pathways by LCA in China. *Applied Energy*, 86(1), pp.S197–S208.

Pandey, K.K., Pragya, N. and Sahoo, P.K., 2011, Life cycle assessment of small scale highinput jatropha biodiesel production in India. *Applied Energy*, 88(12), pp.4831–4839.

Pellegrini, L.P. and de Oliveira, S., Jr., 2011. Combined production of sugar, ethanol and electricity: Thermoeconomic and environmental analysis and optimisation. *Energy* 36(6), pp.3704–3715.

Pereira, C.L.F. and Ortega, E., 2010. Sustainability assessment of large scale ethanol production from sugarcane. *Journal of Cleaner Production* 18(1), pp.77–82.

Petit, L.J., Petit, D.R., Christain, D.G. and Powel, H,D,W., 1999. Bird communities of natural and modified habitat in Panama. *Ecography*, 22, 292-304.

Pilgrim, S. and Harvey, M., 2010. Battles over biofuels in Europe: NGOs and the politics of markets. *Sociological Research*. [e-journal] 15 Available at: <http://dx.doi.org/doi: dx.doi.org/10.5153/sro.2192> [Accessed 12 September 2012].

Portale, E. 2012. *Socio-Economic Sustainability of Biofuel Production in Sub-Saharan Africa: Evidence from a Jatropha Outgrower Model in Rural Tanzania*. Cambridge, Mass: Belfer Center for Science and International Affairs, Harvard University.

Prajapati, N.D. and Prajapati, T., 2005. *A Hand Book on Jatropha Curcas Linn (Physic Nut)*. Jodhpur: Asian Medical Plants & Health Care Trust.

Prueksakorn, K. and Gheewala, S.H., 2008. Full chain energy analysis of biodiesel from Jatropha curcas L. in Thailand. *Environmental Science and Technology*, 42(9), pp.3388–3393.

Puppim de Oliveira, J., 2002. The policy making process for creating competitive assets for the use of biomass energy: The Brazilian alcohol programme. *Renewable and Sustainable Energy Reviews*, 6, pp.129–140.

Quintero, J.A., Montoya, M.I., Sanchez, O.J., Giraldo, O.H. and Cardona, C.A., 2008. Fuel ethanol production from sugarcane and corn: Comparative analysis for a Colombian case. *Energy*, 33(3), pp.385–399.

Ramos, P., 2006. O arrendamento nos lotes dos projetos de assentamento de trabalhadores rurais: Uma possibilidade a considerar?. In 44th Sober Congress. Fortaleza, Brazil 23-27July 2006. Brasilia: SOBER.

Reinhardt, G., Gartner, S., Rettenmaier, N., Munch, J. and von Falkenstein, E., 2007. *Screening life cycle assessment of jatropha biodiesel*. Heidelberg: Institute for Energy and Environmental Research.

REN21, 2012. *Renewables 2011: Global Status Report*. Paris: REN21 Secretariat.

Reporter Brasil, 2009. *Brazil of biofuels: Impact of crops over land, environment and society - sugarcane*. Sao Paulo: Reporter Brazil.

RFA, 2008. *The Gallagher review of the indirect effects of biofuels production*. East Sussex: Renewable Fuels Agency.

Ribeiro, D. and Matavel N., 2009. Jatropha! *A socio-economic pitfall for Mozambique,* *Justica Ambiental & União Nacional de Camponeses*. Maputo: SWISSAID.

Richardson, B., 2010. Big sugar in Southern Africa: Rural development and the perverted potential of sugar/ethanol exports. *Journal of Peasant Studies*, 37(4), pp.917–938.

Romijn, H.A., 2011. Land clearing and greenhouse gas emissions from Jatropha biofuel on African Miombo woodlands. *Energy Policy*, 39 (10), pp.5751–5762.

Romijn, H.A. and Caniëls, M.C.J., 2011. The Jatropha biofuels sector in Tanzania 2005–2009: Evolution towards sustainability?. *Research Policy*, 40(4), pp.618–636.

Rossi, A. and Lambrou, A., 2008. *Gender and Equity Issues in Liquid Biofuels Production: Minimizing the Risks to Maximize the Opportunities*. Rome: Food and Agriculture Organization.

RSB, 2010. Roundtable on Sustainable Biofuels: Principles and criteria for sustainable biofuel production (Version 2.0). Lausanne: Roundtable on Sustainable Biofuels.

RSPO, 2007. *RSPO Certification Systems*. Selangor: Roundtable on Sustainable Palm Oil.

Sano, D., Romero, J. and Elder, M., 2012. Jatropha production for biodiesel in Yunnan, China: Implications for sustainability at the village level. In: A. Gasparatos, P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.205–227.

Scholes, R.J., Archibald, S. and von Maltitz G., 2011. Emissions from fire in Sub-Saharan Africa: the magnitude of sources, their variability and uncertainty. *Global Environmental Research*, 15(1), pp.53–63.

Schoneveld, G.C., German, L.A. and Nutako, E., 2011. Land-based investments for rural development? A grounded analysis of the local impacts of biofuel feedstock plantations in Ghana. *Ecology and Society*. [e-journal] 16(4): 10 <http://dx.doi.org/10.5751/ES-04424-160410> [Accessed 12 September 2012].

Schut, M., van Paassen, A., Leeuwis, C. and Bos, S., 2011. Space for innovation for sustainable community-based biofuel production and use: lessons learned for policy from Nhambita community, Mozambique. *Energy Policy*, 39(9), pp.5116–5128.

Schut, M., Slingerland, M. and Locke, A., 2010. Biofuel developments in Mozambique: Update and analysis of policy potential and reality. *Energy Policy*, 38(9), pp.5151–5165.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabio, J., Tokgoz, S., Hayes, D. and Yu, T.H., 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, 319(5863), pp.1238–1240.

Shackleton, S. and Gumbo, D., 2010. Contribution of non-wood forest products to livelihoods and poverty alleviation. In: E.N. Chidumayo and D.J. Gumbo, ed. 2010. *The Dry Forests and Woodlands of Africa: Managing for Products and Services*. London: Earthscan, pp.63–92.

Shackleton, S., Cocks, M., Dold, T., Kaschula, S., Mbata, K., Mickels-Kokwe, G. and von Maltitz, G., 2010. Non-wood Forest Products: Description, Use and Management. In: E.N. Chidumayo and D.J. Gumbo, ed. 2010. *The Dry Forests and Woodlands of Africa: Managing* *for Products and Services*. London: Earthscan, pp.93–130.

Shumba, E., Roberntz, P., Mawire, B., Mayo, N., Sibanda, M. and Masuka, M., 2011. *Community level production and utilization of jatropha feedstock in Malawi, Zambia and Zimbabwe*. Harare: World Wide Fund for Nature (WWF).

Silalertruska, T. and Gheewala, S.H., 2009. Environmental sustainability assessment of bioethanol production in Thailand. *Energy*, 34(11), 1933–1946.

Singh, R.N., Vyas, D.K., Srivastava, N.S.L. and Narra M., 2008. SPERI experience on holistic approach to utilize all parts of *Jatropha curcas* fruit for energy. *Renewable Energy*, 33(8), pp.1868–1873.

Smeets, E.M.W., 2008. *Possibilities and limitations for sustainable Bioenergy production systems*. Ph.D. University of Utrecht.

Smeets, E., Junginger, M., Faaij, A., Walter, A., Dolzan, P. and Turkenburg, W., 2008. The sustainability of Brazilian ethanol: An assessment of the possibilities of certified production. *Biomass and Bioenergy*, 32(8), pp.781–813.

Sparovek, G., Berndes, G., Egeskog, A., de Freitas, F.L.M., Gustafsson, S. and Hansson, J., 2007. Sugarcane ethanol expansion in Brazil: An expansion model sensitive to socioeconomic and environmental concerns. *Biofuels, Bioproducts, and Biorefining* 1(4), pp.270–282.

Sserunkuma, S.R. and Kimera, H.R., n.d. Impact of EU sugar trade on developing countries. A study with focus on east Africa (Kenya, Tanzania and Uganda). *Germanwatch e.V. Bonn*. [online] Available at: <http://germanwatch.org/tw/zu-afr06.pdf> [Accessed 12 September 2012].

Stromberg, P. and Gasparatos, A., 2012. Biofuels at the confluence of energy security, rural development and food security: a developing country perspective. In: A. Gasparatos and P. Stromberg, ed. 2012. *Socioeconomic and environmental impacts of biofuels: Evidence from developing nations*. Cambridge: Cambridge University Press, pp.3–26.

Stromberg, P., Gasparatos, A., Lee, J.S.H., Garcia-Ulloa, J., Koh, L.P. and Takeuchi, K., 2010. *Impact of biofuels on ecosystem services and biodiversity*. Yokohama: United Nations University Institute of Advanced Studies.

Sulle, E. and Nelson, F., 2009. *Biofuels, land access and rural livelihoods in Tanzania*. London: International Institute for Environment and Development.

Takama, T., Lambe, F., Johnson, F.X., Arvidson, A., Atanassov, B., Debebe, M., Nilsson, L., Tella, P. and Tsephel, S., 2011. Will African consumers buy cleaner fuels and stoves? *A household energy economic analysis model for the market introduction of bio-ethanol cooking stoves in Ethiopia, Tanzania, and Mozambique*. Stockholm: Stockholm Environment Institute.

TaTEDO, 2008. *Bio-fuel powered energy service platforms for rural energy services*. Dar es Salaam: Tanzania Traditional Energy Development Organisation.

TEEB, 2010. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. London: Earthscan

Tigere, T.A., Gatsi, T.C., Mudita, I.I., Chikuvire, T.J., Thamangani, S. and Mavunganidze, Z., 2006. Potential of *Jatropha curcas* in Improving Smallholder Farmers' Livelihoods in Zimbabwe: An Exploratory Study of Makosa Woard, Mutoko District. *Journal of Sustainable Development in Africa*, 8(3), pp.1–9.

Tilman, D., Hill, J. and Lehman, C., 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science*, 314(5805), pp.1598–1600.

Tollefson, J., 2012. Brazil set to cut forest protection. *Nature*, 485(7396), p.19.

Trabucco, A., Achten, W.M.J., Bowe, C., Aerts, R., Van Orshoven, J., Norgrove, L. and Muys, B., 2010. Global mapping of Jatropha curcas yield based on response of fitness to present and future climate. *Global Change Biology Bioenergy*, 2(3), pp.139–151.

Tsao, C.-C., Campbell, J.E., Mena-Carrasco, M., Spak, S.N., Carmichael, G.R. and Chen, Y., 2012. Increased estimates of air-pollution emissions from Brazilian sugar-cane ethanol. *Nature Climate Change*, 2, pp.53–57.

Tsephel, S., Takama, T., Lambe, F. and Johnson, F.X., 2009. Why perfect stoves are not always chosen: A new approach for understanding stove and fuel choice at the household level. *Boiling Point*, 57, pp.6–8.

Turpie, J. and Heydenrych, B., 2000. Economic consequences of alien infestation of the Cape Floral Kingdom's Fynbos vegetation. In: C. Perrings, M. Williamson and S. Dalmazzone, ed. 2000. *The economics of biological invasions*. Cheltenham: Edward Elgar, pp. 152–182.

Tyler, G., 2007. *All-Africa review of experiences with commercial agriculture: The African sugar industry – A frustrated success story*. Rome and Washington DC: Food and Agricultural Organization and World Bank.

UK NEA, 2011. *The UK National Ecosystem Assessment Technical Report*. Cambridge: UNEP-WCMC.

UN DESA, 2007. *Small-scale production and use of liquid biofuels in sub-Saharan Africa: Perspectives for sustainable development*. New York: United Nations Department of Economic and Social Affairs.

UNICA, 2012. *UnicaDATA*. Sao Paulo: Uniao da Industria de Cana-de-Acusar [online] Available at <http://www.unicadata.com.br/index.php?idioma=2> [Accessed 30 July 2012].

Upham, P., Tomei, J. and Dendler, L., 2011. Governance and legitimacy aspects of the UK biofuel carbon and sustainability reporting system. *Energy Policy*, 39(5), pp.2669–2678.

Uriarte, M., Yackulic, C.B., Cooper, T., Flynn, D., Cortes, M., Crk, T., Cullman, G., McGinty, M. and Sircely, J., 2009. Expansion of sugarcane production in Sa ˜o Paulo, Brazil: Implications for fire occurrence and respiratory health. *Agriculture, Ecosystems, and Environment*, 132(1-2), pp.48–56.

de Vries, S.C., van de Ven, G.W.J., Ittersum, M.K. and Giller, K.E., 2010. Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques. *Biomass and Bioenergy*, 34(5), pp.588–601.

Wahl, N., Jamnadass, R., Baur, H., Munster, C. and Liyama, M., 2009. *Economic viability of*

Jatropha curcas L. plantations in northern Tanzania: Assessing farmers' prospects via cost-benefit analysis. Working Paper 97. Nairobi: World Agroforestry Centre.

Wang, Z., Calderon, M.M. and Lu, Y., 2011. Lifecycle assessment of the economic, environmental and energy performance of Jatropha curcas L. biodiesel in China. *Biomass and Bioenergy*, 35(7), pp.2893–2902.

Wanyande, P., 2001. Management politics in Kenya's sugar industry: towards an effective framework. *African Journal of Political Science*, 6(1), pp.123–140.

Watson, H.K., 2011. *Potential to expand sustainable bioenergy from sugarcane in southern Africa*. *Energy Policy*, 39(10), pp.5746–5750.

Whitaker, M. and Heath, G., 2009. *Life cycle assessment of the use of jatropha biodiesel in Indian locomotives*. Golden: National Renewable Energy Laboratory.

Wicke, B., Smeets, E., Watson, H. and Faaij, A., 2011. The current bioenergy production potential of semi-arid and arid regions in sub-Saharan Africa. *Biomass and Bioenergy*, 35(7), pp.2773–2786.

Wijgerse, I., 2008. *The electricity system for a rural village in Mali*. M.Sc. Eindhoven University of Technology.

Wilkinson, J. and Herrera, S., 2010. Biofuels in Brazil: Debates and impacts. *Journal of Peasant Studies*, 37(4), pp.749–768.

Wiskerke, W.T., Dornburg, V., Rubanza, C.D.K., Malimbwi, R.E. and Faaij, A.P.C., 2010. Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shunyanga Region in Tanzania. *Renewable & Sustainable Energy Reviews*, 14(1), pp.148–165.

World Bank, 2011. *A New Slant on Slopes: Measuring the Benefits of Increased Electricity Access in Developing Countries*. Washington DC: World Bank.

WWF-TPO, 2009. *Biofuel Industry Study, Tanzania: An Assessment of the Current Situation*. Dar es Salaam: World Wide Fund for Nature Tanzania Programme Office (WWF-TPO).

Zah, R., Boni, H., Gauch, M., Hischier, R., Lehmann, M. and Wager, P., 2007. Life Cycle *Assessment of Energy Products: Environmental Impact Assessment of Biofuels*. St. Gallen: ETH-EMPA.

UNU-IAS Policy Report

Biofuels in Africa
Impacts on Ecosystem Services, Biodiversity and Human Well-being

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