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Article

The Rise, Fall and Potential Resilience Benefits of Jatropha in Southern Africa

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Abstract: Jatropha is the latest in a list of “miracle crops” that have been promoted in southern Africa for their perceived development benefits. This was based on promises of high yields, low water requirement, ability to grow on marginal land and lack of competition with food. In less than 10 years, tens of thousands of hectares were acquired for jatropha plantations and thousands of hectares were planted, most of which are now unused or abandoned. Overestimations of jatropha yields coupled with underestimations of the management costs have probably been the prime contributors to the collapse of most jatropha projects in southern African. However, a few projects still survive and show signs of possible long-term sustainability. We consider two such projects, a smallholder-based project in Malawi and a large-scale plantation in Mozambique. Though their long-term sustainability is not proven, both projects may increase resilience by diversifying household income streams and contributing to national fuel security. By identifying what seems to be working in these projects we provide insights as to why other projects may have failed in southern Africa and whether there is still place for jatropha in the region. In essence can jatropha still enhance local/national resilience or are jatropha’s benefits just a myth?

Keywords: jatropha; biofuels; southern Africa; Malawi; Mozambique; smallholder scheme; large plantation; resilience

1. Introduction

Between 2000 and 2008, the biofuel feedstock *Jatropha curcas* (L) (jatropha) caught the imagination of national governments, NGOs, international/national development agencies and international investors with interests in southern Africa [1]. These stakeholders perceived jatropha as a "wonder" or "miracle" crop [2] that could solve some of the region's multi-faceted challenges. Jatropha was claimed to offer an attractive package as it could allegedly grow in arid wastelands, provide many local employment opportunities and offer good economic returns to investors, while at the same time increasing national/local fuel security and mitigating climate change. The rapid expansion of jatropha in other developing countries, most notably India, coupled with the perceived potential to produce large quantities of biofuel underpinned these claims. Many of the southern Africa stakeholders mentioned above promoted jatropha with an almost "religious" vigour despite a lack of evidence about the true potential of the crop. Though at that stage no southern African country had in place appropriate policy frameworks to incentivise and regulate biofuel expansion [3], many governments in the region were eager to reap the promised development benefits that jatropha was claimed to offer. In hindsight, it is now clear that most of these early jatropha projects had limited chance of success as they were based on a multitude of incorrect "facts", misinterpretation (or selective use) of the available data, and an overall poor knowledge of jatropha and its agronomy.

Jatropha is by no means the first, and is unlikely to be the last, miracle crop to emerge in southern Africa. Before jatropha, other crops were labelled as miracle crops, and were promoted as potent rural development strategies. Examples include tea, coffee, kiwi-fruit, bamboo, sisal, cotton, tobacco, hemp, *Eucalyptus* spp., sugarcane, *Acacia spp*., *Presopus spp*., soybean, *Moringa oleifera* and L*eucaena leucocephala*. Some have found long-term niches where they provide important income streams to small-farmers (e.g., *Acacia* spp., sugarcane, tea, coffee, tobacco). Yet, many of these crops including tea, coffee, tobacco and cotton have gone through a number of boom-and-bust cycles, where strong initial global demand and local commitment secures high profits early on. Eventually oversupply renders production less lucrative, leading to farmers moving away from the crop, and the cycle restarting [4]. In many instances, unintended latent negative social and ecological impacts occurred such as the crops becoming naturalized in their new habitat and becoming invasive alien plants (IAPs). Though some of these IAPs continue to provide large economic benefits (e.g., *Acacia mearnsii* and *Eucalyptus* spp.), in many cases they have created huge environmental problems and have proved almost impossible to eradicate (e.g., *Acacia mearnsii, Leucaena leucocephala* and *Prosopis* spp.) [5–7]. Jatropha is considered a noxious weed in parts of Australia and has been targeted for biological control [8] and was banned in South Africa precisely due to this concern [9]. However, it remains contentious whether jatropha is actually invasive in southern Africa [10,11]. Some species proved to be climatically unsuitable in some areas, such as hemp in parts of South Africa where daylight duration in summer is too short for optimum yield [12]. In other cases, technological advances rendered products derived from crops redundant or uneconomic, e.g., the replacement of sisal rope by synthetic products [13]. In other cases (e.g., *Leucaena leucocephala*), the positive benefits that actually materialised were far fewer than those originally expected due to incorrect assumptions and background research, as well as unanticipated pests and diseases [14]. In a similar manner, soybean production has expanded rapidly over the past few years in southern Africa, mirroring trends in Brazil. However, the Brazilian experience has raised concerns over soy's environmental and social impacts due to the extensive land areas converted, the relatively low yields/income returns per unit area and the dominance of large producers [15,16].

What has put jatropha in a league of its own among miracle crops was (a) the perception that the potential market for jatropha could be effectively unlimited (*i.e.*, liquid fuel for transport) provided that the crop could be produced in a cost-competitive manner compared to conventional transport diesel; and (b) the sheer speed of jatropha's rise and fall as a biofuel crop.

A key feature of the jatropha hype (and other wonder crops for that matter) is not only whether they can actually live up to their claims, but also the vigour with which their proponents promote them before their true potential has been proven. It has been suggested that the vested interests of many stakeholders in India may be partly responsible for the degree of support [17]. Our own experience suggests that the same may well be true for southern Africa.

Considering the above, the aim of this paper is to offer an overview of the factors that led to the rise and fall of jatropha production in southern Africa and to elucidate the role, if any, that jatropha still can play in promoting development in the region. Considering the wide scope of our paper, we employ a combination of methodologies (Section 2). We start by unravelling some of the local and international circumstances that created a fertile ground for the jatropha hype in southern Africa (Section 3). We then show how a series of eventually unmet expectations and unforeseen global feedbacks were instrumental for the eventual decline of the jatropha sector in the region (Section 4). Subsequently, we identify the factors that have contributed to the continued operation of two very different jatropha projects; a smallholder-based project in Malawi (BioEnergy Resources Ltd., BERL) and a large-scale plantation in Mozambique, (Niqel Lda., Niqel) (Section 5). In particular, we tease out some of the operational characteristics of the two projects that can potentially increase the resilience of (a) local communities to livelihood shocks; and (b) national economies to energy supply shocks (Section 6).

2. Methodology

Our paper tackles four interlinked topics:

- Reconstruct the rise and fall of the jatropha sector in southern Africa;
- Identify the reasons behind this trajectory;
- Identify what characteristics have made some jatropha projects persist despite widespread project collapse;
- Put these findings into perspective to understand whether jatropha still has a role to play in southern Africa.

To reconstruct the rise and fall of the jatropha industry in southern Africa, as well as the main contributing factors, we undertake a comprehensive literature review (Sections 3 and 4). This is complemented by our extensive experience visiting numerous jatropha projects in the region [18,19].

We consider the entire region [1] as, with the exception of South Africa, it has similar socioeconomic, land tenure and farming systems. Furthermore, most jatropha projects in southern Africa have been located in areas of dry forest (miombo), which has similar underlying ecology and land uses throughout the region [20,21]. It should be noted that the jatropha hype (and the biofuel hype for that matter) did not happen only in southern Africa. Global situations coupled with local circumstances resulted in a conducive environment for a new biofuel crop in southern Africa. For this reason, while we mainly review studies from the region, we complement them where necessary with global studies or studies from other parts of the world that experienced significant jatropha expansion such as India.

In order to identify those characteristics that can increase the viability of jatropha projects, we conduct empirical research. In early 2013, we consulted widely with researchers and practitioners throughout southern Africa to identify jatropha projects that are still operational, show signs of long-term viability and are representative of both small- and large-scale management models. The general feedback indicated a wide-scale collapse (or near collapse) of jatropha projects throughout the region, including most of the projects in Mozambique and Zambia, the two countries in the region that possibly experienced the greatest jatropha expansion. The two projects that met our selection criteria were BERL in Malawi and Niqel in Mozambique. BERL is a smallholder-based jatropha project with farmers predominantly growing jatropha as a hedgerow that surrounds their crop fields. Niqel has adopted a commercial plantation model due to the low population density and relative abundance of land in the area.

The empirical data was obtained during a field campaign in March 2013 through (a) key informant interviews with company personnel and local stakeholders; (b) a household survey that contained qualitative and quantitative questions about the role that jatropha played in household livelihoods. For the Niqel study, we administered the questionnaire to 22 full-time employee households, 13 part-time labourer households and 46 households not involved in the project. For the BERL study, we visited five smallholder villages in Machinga district and interviewed 55 jatropha growing and 41 non-growing households. The key findings of this exercise are discussed in Section 5.

We synthesize these results (Sections 3–5) by employing concepts from resilience theory to understand possible benefits from jatropha introduction. To our best knowledge, resilience theory has not been used so far to study biofuel-related phenomena.

3. The Rise of Jatropha in Southern Africa

3.1. The Conducive Environment for a New Biofuel Crop in Southern Africa

In 2000, jatropha was practically unknown to academics, policy-makers and investors globally, and in southern Africa in particular. However, by 2007, the Global Exchange for Social Investment (GEXSI) estimated that 111,000 ha of jatropha had been planted in 52 projects within southern Africa. They forecasted a total of 2.2 million hectares to have been planted in the region by 2015 [22]. Our own research during that period suggests that the number of projects reported by GEXSI was rather conservative as we identified at least 66 jatropha projects in the region [18]. Although the number of projects is underestimated, the actual area of land under jatropha cultivation seems to have been grossly exaggerated by some companies. It was found that in 2012 only 3.6, 12.9 and 3.2 per cent of the authorised land for biodiesel feedstock production (predominately jatropha) had actually been planted in Mozambique, Zambia and Tanzania, respectively [23].

Up until jatropha's rise in popularity in about 2000, there were few trials and little experience in growing jatropha as a domestic crop. Actually, the main uses of jatropha were medicinal or as a livestock proof hedgerow [24]. In essence, there was no local or global experience on how to grow jatropha for oil production and limited global experience about its agronomic properties. Yet, a number of scientific publications and reports ("grey literature") presented the potential benefits from growing jatropha, including the supposed agronomic advantages of the tree as well as the environmental and social benefits that could accrue from growing jatropha [25,26]. Globally, and especially in India, there was wide scale jatropha expansion, with arguments being made for growing jatropha both in plantations and in small-holder and/or small-scale schemes [27–29].

Even though the jatropha hype was not isolated within southern Africa, the timing was opportunistic for local realities and international circumstances to contribute to the creation of a dominant mind-set conducive to jatropha's widespread introduction in the region. In retrospect, we can identify six interlinked factors that contributed to the creation of this attractive environment.

First, fuel prices were increasing exponentially, positioning biofuels as an economically feasible source of renewable energy that could boost national and local energy security [30]. It is important to remember that almost all countries in the region import all (or most) of their transport fuel. This is a significant burden to the trade balance, especially in landlocked countries such as Malawi, Zambia and Zimbabwe, or in remote areas of countries such as Mozambique where access to fuel is difficult [31,32]. While some countries such as South Africa and Zimbabwe had some experience with liquid biofuels, only Malawi was still blending biofuels in the mid-2000s [33]. However, the debate about peak oil and increasing fuel prices reopened discussions on alternative transportation fuels;

Second, the agricultural sector and as a consequence rural development efforts, were stagnating in southern Africa [34]. Any initiative that could help alleviate rural poverty and modernise the agricultural sector was therefore of huge interest to southern African governments, development-focused NGOs and international cooperation agencies [35]. In fact, rural development and pro-poor benefits have been identified as particularly important drivers for the development of biofuel policies across southern Africa [36–39].

Third, biofuels were identified as a potentially important climate change mitigation option due to the escalating global concerns over climate change [40–43]. Early biofuel life cycle assessments (LCAs) disregarded the effect of land use and cover change (LUCC) on the greenhouse gas emissions (GHG) [44] but, biofuel-related direct and indirect LUCC effects, including for jatropha in the African context [45–47], were eventually shown to be responsible for significant GHG emissions from biofuels [42,44],. At present southern African countries have not been required to curb their GHG mitigation (non-Annex I countries). However, biofuels' perceived mitigation potential was an important driver from investors from developed countries who were prepared to invest in jatropha production for export into developed countries where policy-makers and the general public were still seeing biofuels as a largely carbon-neutral fuel with many development co-benefits [43]. Furthermore, Clean Development Mechanism (CDM) funding allowed jatropha grown on already deforested or degraded land to be considered as a form of reforestation giving thus another incentive [48,49].

Fourth was the creation of international biofuel markets, particularly in the European Union (EU). In 2009, the EU ratified the Renewable Energy Directive (Directive 2009/28/EC) that established a biofuel-blending mandate that required 10% blending of biofuel into conventional transport fuel. The Directive stipulated that biofuel/feedstock imports could meet the excess demand if the blending targets were not met through internal biofuel/feedstock production [50]. This was perceived by investors as an opportunity to invest in biofuel production in developing countries. Global assessments pointed to Africa, and particularly southern Africa, as the region with the highest bioenergy potential due to a combination of low population density, reasonably good climatic and soil conditions and vast areas of allegedly underutilised land [51–53]. Studies about the bioenergy potential of jatropha identified extensive areas (marginal and otherwise) in southern Africa that could potentially accommodate jatropha without competing with food production and conservation areas [54].

Fifth, jatropha was claimed to have an array of environment and development co-benefits (refer to Section 4.1). A number of the early jatropha investments were based on corporate social responsibility funding from the private sector (e.g., TNT in Malawi) or by development agencies promoting socially and environmentally sustained development in Africa (e.g., German GTZ).

Finally, there was already an extensive interest in jatropha in other parts of the world, particularly in India [17]. Investors, NGOs and government officials used this interest to justify jatropha projects in southern Africa based on the flawed assumption that the Indian jatropha projects were successful.

3.2. A Reconstruction of Early Jatropha Initiatives in Southern Africa

Jatropha was promoted in two parallel streams. The private sector was driven by the prospects of high economic returns, a "*new oil rush*" as some media phrased it [55]. Southern Africa governments and development agencies saw jatropha as a mechanism to tackle rural poverty, a major concern of the region, with the added advantage of global climate benefits (refer to Section 3.1). It is, however, difficult to reconstruct an accurate history of jatropha introduction in southern Africa as most projects were independently initiated by the private sector.

In South Africa, one of the early key players was D1 Oils S.A. (Pty) Ltd, a subsidiary of D1 UK Ltd/Imvubu Agric Enterprises (Pty) Ltd (D1). The company commissioned a scoping report for jatropha introduction in southern Kwazulu-Natal [56]. The full environmental impact assessment (EIA) was concluded in November 2005 [57]. By that time, the sufficient interest in jatropha by the KwaZulu Natal Department of Agriculture had prompted the Water Research Commission (WRC) to undertake a detailed study of jatropha water use. For this purpose, jatropha trials were initiated in 2004 at the Ukulinga research station in Pietermaritzburg [58]. Eventually, the cultivation of jatropha was effectively banned in South Africa in 2007 over fears of invasiveness. As a consequence, D1 relocated their plantations to Swaziland and Zambia. The Swaziland plantation was highly contentious and received extensive unfavourable media reports [59] while the Zambian plantation never reached its planned size. Eventually D1 closed its southern African operations in about 2012.

In Zambia, Marli Investments and Oval Biofuels were two of the early promoters of outgrower-based and smallholder-based jatropha production. The Biofuels Association of Zambia actively promoted jatropha during these early stages while the past president of Zambia, Dr. Kenneth Kaunda, was rumoured to be a board member of Marli. He actively supported jatropha growing and gave the project credibility with small-scale farmers [60,61]. Marli began planting jatropha in 2004. Their approach was to develop contractual arrangements with smallholder farmers to plant a few hectares of jatropha on their farm [40]. The growers signed long-term contracts, and in return these companies were to provide agricultural inputs and funding until seed production started. By 2009, they were claiming extensive areas planted, however field visits found that farmers had typically planted only 1.6 hectares on average, while much of the initial support they had received from the companies had ceased [3,61]. A number of other companies also initiated projects, e.g., Southern BioPower and D1, but most projects used only a portion of the allocated land, with some not even progressing beyond the planning stage [23].

Mozambique established a comprehensive and rather successful biofuel strategy in 2009 [62]. However the interest in jatropha started as early as 2004 when the government started distributing jatropha seeds to farmers and the president was quoted claiming that "*Mozambique should be an oil-exporting country*", and that "*Jatropha should be planted on all unused soils*" [38]. It was, however, the private sector that drove most of the jatropha enthusiasm. By December 2008, the government of Mozambique had received 12 official jatropha investment proposals amounting to USD 298 million for a total of 179,404 ha (1661 USD/ha on average), with a further 19 jatropha projects not formally logged with government [38]. The eventual fate of all these informal projects is not well documented, but it is probable that many never developed beyond the planning phase [23]. It should be noted that while most Mozambique projects tended to follow a large plantation model, there were a few small-scale projects, e.g., Envirotrade and FACT Foundation [63,64].

Malawi was the only country in southern Africa that produced and blended liquid biofuels (sugarcane ethanol) in significant quantities when the jatropha hype erupted. Malawi differs from most other countries in the region as it has is a high population density with limited availability of land. By 2005, the Biodiesel Agricultural Association had been formed and was advocating the cultivation of biodiesel crops. It was apparently promoting the planting of jatropha on behalf of D1 Oils Africa (Pty) Limited [65]. Although a few plantation projects were initiated in Malawi, the main focus was on smallholder projects, often planting jatropha as hedgerows [66]. Janeemo, a Scottish-funded initiative has been supporting the incorporation of tree crops (including jatropha) into the smallholder sector since 2007 [67]. However, BERL has been the main company to promote the wide-scale cultivation of jatropha in smallholder hedgerows, and is the only major market for jatropha seeds in the country (Section 5). Currently, sugarcane ethanol is still dominating the market with jatropha production amounting to just a fraction of the biofuels produced in the country.

Botswana has also been considering jatropha, but has taken a more cautious approach than other countries in the region. Most jatropha related-activities in the country remain at the research level, as the government of Botswana needs appropriate knowledge before embarking on a more wide-scale expansion campaign. Most of the ongoing research efforts are promoted by the Japanese International Cooperation Agency (JICA) [68].

Namibia embarked on a number of jatropha projects in the moister northern regions, with four main projects reported during the early stages of the jatropha expansion [68]. Private investors worked with traditional authorities to establish plantations on communal land [69]. One such project later abandoned its plantation, eventually removing the already planted trees as it was not possible to reach an agreement with the government over land tenure (Johan Breytenbach personal communications). Another, irrigated project suffered from high levels of tree mortality due to termites [70]. A Strategic

Environmental Assessment was commissioned in 2010 which suggested only low yields could be expected and that jatropha was unlikely to be financially viable [71]. Jatropha growing has now apparently been banned awaiting further research [72].

In Madagascar, a number of large-plantation projects were initiated. Madagascar actually experienced some of the most extensive large-scale land allocation for jatropha in the region (928,610 ha) [73], but it is not actually clear how many of these projects actually materialised. Nevertheless, at one point, GEM Biofuels held claim to the biggest biofuel project, at least in Africa, with 452,000 hectares allocated [73]. Tozzi Green, an Italian-led investment in the central part of Madagascar, aimed to grow jatropha in 100,000 hectares and boasted the largest jatropha nursery in the continent.

Zimbabwe, with its political isolation, was very keen on jatropha as a mechanism for ensuring some level of national fuel security in a country that regularly faces fuel shortages [74]. Even though there was some jatropha expansion, most of the biofuel efforts in the country have been dominated by sugarcane ethanol [75–77].

4. The Decline of the Jatropha Industry in Southern Africa

4.1. Jatropha's Unmet Expectations in Southern Africa

In order to understand why jatropha uptake was so swift and strong, but also why projects ended up not meeting their initial expectations, it is useful to consider the claims that were being made about jatropha's ability to produce biofuels and deliver rural development benefits to southern Africa. We have identified five interrelated claims that eventually produced the misconceptions about jatropha's potential.

First, the biggest selling point of jatropha in the region was the unproven claim of high oil yields [78]. The Jatropha Organization of South Africa at the time of writing still claims on their website [79] that jatropha can produce 16.6 tonnes of seed per hectare and 5.8 tonnes of oil per ha, with individual trees producing up to 40 kg of seeds per tree. When reviewing 12 Mozambique biofuel projects, it was found that the average expected yield was 2.64 tonnes of oil per hectare per year [38]. Based on a 33% oil yield, this would represent 8 tonnes of seeds per hectare per year (though there was no breakdown in the study of how this number was obtained or the variance between individual projects) [38]. A 2006 USAID report for Madagascar quoted oil yields of 2.10–2.60 tonnes per ha, with the implication that thousands of tonnes of jatropha oil were potentially available [80]. D1 in their South African EIA anticipated yields of 5.2 tonnes of seed per hectare per year. It was estimated that some investors would need to achieve over 35 tonnes of seeds per hectare to reach their projected oil yields [78]. Even the lower-end of those early yield expectations suggested that jatropha would be yielding two to three times more oil per unit land compared to other annual oil crops such as soybeans or sunflower. Although only a few examples have been given, it appears that across the industry early expectations were for yields of five tonnes of jatropha seeds per hectare (or more) [81]. These optimistic yields found their way as assumptions, and perhaps received credibility, in academic studies. For example, early LCAs essentially based their calculations on predicted yields, as at that point there were few (if any) fully operational projects. For example, early jatropha LCAs assumed yields as high as 12–13 t/ha in Thailand [82,83], 6–11.25 t/ha in India [84], 5 t/ha in Malaysia [85], 5 t/ha in China [86] and 4 t/ha in the Ivory Coast [87]. Even more worrying is that still some LCAs assume yields as high as 11.6 t/ha in Colombia [88], 9.75 t/ha in China [89] and 8 t/ha in Tanzania [90]. These are just some of the LCAs that assumed high jatropha yields and have been published in highly cited energy journals. It may be the case that inflated jatropha yields entered (and are still entering) the academic literature, thus giving an appearance of academic credibility to these so far unrealised yields.

A second claim that appealed to many southern African governments was that jatropha could grow on marginal/degraded land and in arid conditions [24,25,91]. Some studies claimed that jatropha could grow in areas with as little rainfall as 250 mm per year [91,92]. This led many southern African governments to believe that jatropha would be able to grow in areas too dry for conventional crops. However, subsequent experience in southern Africa and elsewhere has shown that even though jatropha can grow in water-limited conditions, the final yields are much lower than those achieved when jatropha is grown in good conditions [78,93–95]. A number of further unsubstantiated claims around jatropha included pest resistance [25,96], ease of management [24], rapid period to first harvests [24,25,91] and ability to fix nitrogen [97]. All these added to the perception that jatropha may be a perfect crop for the agro-ecological and climatic conditions encountered across southern African.

A third claim closely linked to the previous one was that jatropha would not pose a threat to food security. This was mainly based on jatropha being (a) toxic and thus inedible; and (b) it's supposed ability to grow on wasteland. In truth, few projects in southern Africa were initiated on waste-land, with most of them actually being established on good agricultural land [39]. In this sense, jatropha competes with food crops for land and other agricultural inputs such as labour, capital and water [98]. This is essentially the same for most other cash crops, so the relative return to land and labour is a better measure of the crop's value than its direct competition with food crops (see below).

A fourth claim was that jatropha is in effect a high-value crop from which large profits could be made. For example, Goldman Sachs touted jatropha as the cheapest feedstock for commercial biofuel production [99]. This claim of high returns was certainly the message that was being presented to early investors. In fact, a number of the large biofuel companies such as D1, GEM and Sun Biofuels were listed companies on various stock exchanges including the London Stock Exchange [18], whilst others such as Bioshape, though unlisted, still relied heavily on international investors for funding. In a sense, by capitalising on jatropha's perceived social and environmental co-benefits, jatropha was being "sold" as both an economically sound and a socially responsible investment.

The fifth claim was jatropha's high job creation and rural development benefits. For instance, D1 in its scoping study claimed that a mere 15,000 ha of jatropha could alleviate 50% of the region's unemployment, projecting three permanent jobs for each hectare planted. However, in the full EIA this was modified to 0.37 jobs per hectare. In Mozambique, it was found that projects were anticipating 0.14–0.21 jobs per ha [38], whilst the government of Mozambique projected 0.33 jobs per hectare [100]. Considering that most large-scale jatropha projects in the region have collapsed it is difficult to provide estimates of their actual employment generation potential. Our analysis of Niqel plantation in Mozambique (Section 5) suggests that employment benefits can be as low as 0.11 permanent jobs per hectare, though there will be a large number of low paying seasonal jobs (*i.e.*, temporary jatropha pickers during harvesting).

4.2. The Factors behind Jatropha Project Collapses in Southern Africa

The claims described above fuelled the impressive expansion of jatropha in southern Africa. However, the decline of the jatropha sector was incredibly rapid as well. To our best knowledge, since 2008, most jatropha projects in the region have either partially (or totally) collapsed, have substantially reduced their levels of investment, or have been sold out to new investors at a fraction of the initial investment [19,23,101].

Usually the collapse of these projects has left local communities worse-off through a combination of loss of land tenure, access to natural resources and missed income opportunities [19,39,78,102]. ESV in Mozambique is particularly notorious as its labour force remained unpaid for approximately 16 months, whilst government officials tried to persuade them to continue their work. The project was eventually sold to new investors and the current status is unknown [19], however there is no evidence of large scale oil production coming from the project. Bioshape in Tanzania had a similar fate with a spectacular and well-documented collapse amidst allegations that the project may have been a front for illegal hardwood harvesting [59,103].In 2011, Sun Biofuels effectively stopped its operations in Mozambique and Tanzania affecting negatively the livelihood of local communities [59,102]. D1 Oils and GEM Biofuels also disinvested from the region during the same period after their shares collapsed [104]. GEM biofuel closed its operations and declared their plantation to have zero asset value [105]. Marli in Zambia seems to also have quietly faded away effectively stopping support to farmers by 2009–2010 when southern projects [3] and northern project [61] were visited. Tozzi Green in Madagascar went through a major restructuring in 2013 amidst political instability in the country and allegations of land-grabbing. The company effectively halted further jatropha cultivation due to low achieved yields, discontinued its jatropha nursery, suspended its ongoing EIA and laid off several workers and permanent staff (Mananjo Johanson, personal communication).

The reasons behind the collapse of jatropha projects in southern Africa have not been rigorously researched but it is clear that in most cases these projects lacked financial viability and had low overall profitability. Five interrelated factors contributed to this poor financial performance:

- Changes in investor behaviour. During the outset of the 2008 financial crisis investors withdrew funds from risky foreign investments (suddenly jatropha investments were viewed risky) [106]. Additionally the emerging food-*vs.*-fuel and land-grabbing debates combined with the increasing scrutiny over biofuels' social and environmental benefits, meant that biofuels were no longer being portrayed as socially and environmentally appropriate investments [36,105,106]. This further undermined investor support [36,104,107];
- Time lags in production. Initial projections were that yields would materialise as early as two years after planting, which proved to be optimistic. Furthermore, several projects in southern Africa took longer than expected to finalise planting due to the complexities involved in acquiring land (largely communal land), and the extent of labour and resources needed to clear the land [64,107];
- Overestimated yields [108,109]. Indications from site visits and the available literature suggest that none of the jatropha projects in the region have been achieving financially viable yields, despite most trees now being older than the productive age of three years [39]. It has been pointed that this may be partly due to many projects being established in areas with low jatropha potential [64];

- Underestimated labour costs. Jatropha appears to require far more labour than initially anticipated. Picking is particularly labour intensive, becoming more intensive for lower yields [110];
- Underestimated maintenance costs. Jatropha has not lived up to expectations of low maintenance needs. Many projects were susceptible to insect pest and required unanticipated spraying [64,109]. Jatropha plantations also need to be kept weed-free during early stages if rapid growth is desirable [58];
- Global fuel prices. Global oil prices more than quadripled between 2000 and 2008 reaching an all-time high of USD 145/barrel (July 2008). While several jatropha projects aimed to capitalise on high oil prices, the sudden oil price decline (reaching about USD30 per barrel by the end of 2008) essentially made jatropha-based fuels uncompetitive for export within just a few months;
- High transport costs. Many jatropha projects were/are located in remote rural areas making transportation of the feedstock from project sites expensive. Furthermore, the cost (transort and personnel) of collecting small quantities of seeds from scattered smallholder farmers ended up higher than was anticipated (Section 5), In countries such as Mozambique and Malawi, high fuel prices during the oil price spike might have reduced farm gate jatropha prices due to high transport costs affecting the profitability of jatropha [111].

Weak national institutions and the lack of appropriate biofuel policies and legal frameworks have also been blamed for affecting the viability of jatropha projects, mainly related to lack of support for the development of local markets [112]. At the onset of the jatropha hype, no country in southern Africa had a mature framework to regulate the biofuel sector [36]. However, it is difficult to quantify the extent to which institutional failures resulted in the collapse of jatropha projects. The scarce available evidence, coupled with expert interviews conducted by the authors, suggested that institutional failures contributed to project collapse, but was probably not the deciding factors since similar fates affected projects growing jatropha for both the international and national markets. For example despite the support that jatropha received in Zambia (Section 3.1), the government still subsidised imported fossil fuels and delayed mandating a standard price for biodiesel (Thomas Krimmel, personal communication). This basically made it uneconomic for jatropha ventures to operate, what one interviewee termed “commercial suicide”. However, Zambia already has the most expensive diesel fuel in the region, which should have given jatropha-based biofuels some competitive advantage [110]. In Malawi, the slow progress in passing appropriate policies for biodiesel has been considered as a key risk faced by jatropha projects (Abbie Chittock, personal communication). In Madagascar, the political instability and corruption delayed significantly the business cycle of jatropha companies and the development of markets (Mananjo Johanson, personal communication).

It is interesting to note that the lack of proper policies did not only affect the viability of jatropha projects, but also failed to protect local populations after project collapse. For example, in several countries in the region (e.g., Mozambique, Tanzania, Zambia) the process for allocating land to large-scale agro-industrial developments is lengthy, complicated and does not always safeguard the customary rights of local communities [113,114]. This has the double jeopardy of (a) delaying the investment process (with whatever effects it might have on project viability); and (b) compromising the livelihoods of local communities due to loss of access to land. The latter manifested clearly after the collapse of Sun Biofuels and Bioshape in Tanzania, among several other examples [100,103].

4.3. Lessons Learnt from the Collapse of the Jatropha Industry in Southern Africa

The recent boom-and-bust of jatropha resembles that of other miracle crops and is well recognised in the development literature. A number of lessons can be drawn from the jatropha experience in southern Africa and this may help reduce the risks of failure when the next miracle crop is promoted in the region. Some of the salient points include:

- Full and scientifically rigorous trials (both in research stations and on-farm) must be undertaken in the expansion region prior to large-scale promotion of the crop;
- Different physiological features can impart some plants with some competitive advantage in different environments. However, any claim that a particular crop can perform far better in a certain condition than competing crops would require sound scientific support before being accepted. The claim that a single crop can perform well over a wide variety of climatic and agroecological conditions should be treated with extreme caution. Though many species can grow over a wide range of conditions, it is unlikely that they will be economically viable over all these conditions;
- Where multiple benefits are claimed, it is not always feasible to access all benefits. In addition, different benefits may be in conflict with each other. For example, while jatropha is able to grow on degraded/marginal land or in water-limited environment, this takes a toll on its ability to produce high yields;
- Large variations in performance should be expected if a “wild” species is to be used. Baseline productivity predictions should be based on the mean performance of the species in the relevant agroecological zone, and not on the performance of a few high performing plants. In addition, appropriate breeding and selection should be undertaken early on in the process;
- There are almost always unforeseen environmental and social consequences when introducing new crops. Significant effort needs to be invested, to understand in an integrated manner what these consequences may be. EIAs, Strategic Environmental Assessments (SEA) or Sustainability Assessments should aim to capture these potential impacts [115];
- Euphoria over the potential of new crops seems to overrule more nuanced and cautious approaches to crop introduction. This might stem from the effort of crop promoters to sell the concept to potential investors. Investors need to access unbiased and independent data, and undertake appropriate risk assessments before entering large-scale investments;
- Governments should be more involved from the onset in exploring the potential of new wonder crops. If such crops are deemed beneficial then governments, through appropriate policies, should regulate their introduction and support the development of markets and infrastructure.

5. Lessons from Two Operational Projects

In March 2013, we visited two of the few jatropha projects that have not collapsed and show some signs of long-term viability in southern Africa: BERL in Malawi and Niqel in Mozambique. BERL is a smallholder-based jatropha project with farmers predominantly growing jatropha as a hedgerow that surrounds their crop fields. Niqel has adopted a commercial plantation model due to the low population density and relative abundance of land in the area. The relative success of these projects raises the question of whether jatropha is a "*de-facto*" unsustainable land use, or are there circumstances in which jatropha can be a viable land use option. More importantly: if jatropha can be a viable option, what are the conditions under which it is likely to succeed? Table 1 summarises the key features of the two projects as identified through expert interviews and household surveys (Section 2).

The long-term future of both BERL and Niqel still depends on whether the seed yields from mature trees will be sufficiently high and reliable to ensure their financial viability. This is an issue that only time will tell. However, there are several common features shared by the two fundamentally different models that may help identify circumstances under which jatropha production may be viable in southern Africa (though many of these results may well have more general applicability).

Both projects are based on initial assumptions of relatively modest yields. For Niqel, the economic analysis undertaken during the EIA was based on a yield of 3 tonne of seeds per hectare [116]. BERL made financial assumptions based on a yield of 0.85 kg of seeds per tree, which would be translated to one tonne of seeds per hectare given the same tree spacing used by Niqel. BERL, however, hopes to achieve yields of 1.5 kg of seeds per tree (1.9 t/ha). In both cases, these yields are far more modest than those suggested in some of the popular literature, or used as the basis of other projects in the region (Section 4.1). Both projects have therefore based their operations around modest expectations of yield and corresponding economic returns, and have structured their overheads accordingly.

For Niqel, the per hectare establishment cost would appear to be substantially lower than the norm for block plantations of jatropha. Though data for most projects is not publicly available, it is clear that some of the other larger initiatives had high and expensive corporate overheads, with many directors and other highly paid staff. For example the publically available annual reports of GEM Biofuels report total annual earning of GBP636,000 in 2008 for its three directors, including share options. D1 Oils maintained a staffed office in Randburg (South Africa) for many years after closing their South African operations. On the other hand, Niqel's operation could be described as "lean and mean" with a small focused management team concentrating on getting the plantation established and running it smoothly while its senior staff had been familiar with working in large-scale agriculture in southern Africa. Niqel also has a well-run and maintained fleet of heavy equipment, which has very low levels of downtime. Niqel therefore claims that it has the lowest establishment costs per unit land planted compared to similar jatropha projects in southern Africa. In addition, they have been more successful than most large-scale jatropha initiatives in the region based on area actually planted, boasting 2250 hectares planted to date.

For BERL, the smallholder model adopted means that many of the cultivation costs (and risks) are borne by the smallholder farmers, and not by BERL itself. However, BERL had until recently a relatively large network of extension staff to support the smallholders. Use of Clean Development Mechanism (CDM) financing as well as "soft" loans and support from corporate social responsibility programs assisted the funding of these extension activities. However, since June 2013, most of this extension staff was retrenched, with BERL changing its focus towards a core operation of jatropha oil extraction. This change was made to ensure long-term financial viability given changes to their funding regime. It also represented an organisational shift from promoting jatropha growing to being a viable enterprise based on oil seed pressing. To increase its viability given the limited quantities of jatropha seeds, BERL has diversified its oil extraction operations to include alternate crops such as sunflower seeds (for cooking oil) using the same processing infrastructure.

Table 1. Summary characteristics of BioEnergy Resources Ltd. (BERL) Malawi and Niqel Mozambique.

	BERL Malawi	**Niqel Mozambique**
Project type and scale	Smallholder-based project. Trees are mainly planted as hedgerows in small family farms and are managed by farmers themselves. Currently 30,000 smallholders are involved throughout Malawi, with the intent to increase this over time. Most of the 90 buyers/extension staff were retrenched in June 2013.	Large-scale commercial plantation. Trees are planted in block plantations and managed by paid labour. 2250 ha are planted in a concession of approximately 7500 ha at Grudja, Mozambique. 250 permanent staff with added casual labour hired for harvesting.
Ownership	Trees are owned by farmers and are mainly grown as hedges in family farms. BERL is owned by a private company linked to the Dutch TNT.	Trees are owned by Niqel on leased land. Niqel is a private, listed company in Mozambique and is linked to the Dutch Dikon Holdings.
Role of company	Purchases jatropha seeds through a network of buyers across Malawi and extracts jatropha oil. Extension activities were discontinued in June 2013.	Grows jatropha trees, harvests seeds and extracts oil (from 2014).
Demography and location	High population density. Some of the villages visited in Machinga district were remote. Other BERL villages are located in more accessible areas. Mean household size was 5.6 (2.1 SD) with 2.8 (1.6 SD) children under the age of 15.	Low population density. The plantation is located 20 Km from the closest tar road. Farming households are dispersed around the plantation, with only one small formal village located in the vicinity of the plantation. Mean household size was 7.5 (3.5 SD) with on average 3.8 (2.5 SD) children below the age of 15.
Farming practices and livelihoods of local communities	Wall-to-wall permanent small family farms: 0.1–2.5 ha (1.7 ha mean). All farmers grow maize, with a mix of other crops. Production is largely for subsistence purposes. Mean income from sales of excess crops is USD 38 per year. Most households experience 2–6 months of food shortage per year.	Non-permanent farms using slash-and-burn agricultural practices: 0.5–14 ha (4.0 mean). Only 11.5% of the total land is under cultivation, with the rest being woodland. Mean income from agricultural sales of excess crops is USD 83 per year. Most households experience 4–5 months of food shortage per year.
End-use and expected blending targets	Jatropha oil to be directly blended into national diesel fuel up to a maximum of 9%.	Jatropha oil to be shipped to Maputo where it will probably undergo transestification. Niqel could potentially produce half of the total biodiesel needed to achieve the 3% biodiesel blend mandated by the government of Mozambique.
Yields	First harvests were recorded in 2012–2013. Quarter-year yields range widely: median is 0.07 kg/tree, but few farmers report over 0.4 kg/tree. BERL target is 1.5 kg/tree per year at maturity, which is the equivalent of 1.9 t/ha (at 1250 trees/ha).	First formal harvest obtained in 2012–2013. Yield increased from 0.16 t/ha in the first year, to 0.4 t/ha in the second year. Target is 3 t/ha during maturity.

Table 1. *Cont.*

	BERL Malawi	Niqel Mozambique
Proportion of crop land converted to jatropha	At present a 500-jatropha tree hedge could take up 7% of the average area of a family farm. This might increase slightly as trees grow.	Approximately 6% of the total community land is converted to jatropha, reducing the land per farmer from an estimated 27 ha, to 25 ha. However, this is expected to have no impact on the area under crop production, as labor (and not land) is the scarce factor for food production.
Impact on food security	At present seems minimal though some cropland is lost to jatropha. Possibly there is a competitive interaction between jatropha trees and food crops. Additional income will enable farmers to purchase food during the most food insecure months.	The plantation does not limit land for home food production. Plantation policy limits hired labour to one family member per household, and respondents say they can maintain their crop production. Additional income from labour allows households to purchase other household items without need to sell food crops (or might act as a safety net during droughts).
Impacts on woodland and access to forest products	No (or minimal) direct impact on woodlands as the land under jatropha cultivation was already converted to agriculture. Indirect effects might be possible but this will depend on the location of the farm. Indirect impacts for the whole Malawi would be very difficult to estimate due to the outreach and disaggreagated nature of BERL's operations.	High direct effects on woodlands as it is expected that 5500 ha of woodland will be lost if the project reaches it maximum size. Given the low population density, current woodland loss does affect access to woodland products (e.g., timber, medicinal plants).
Infrastructure investment	BERL has established an oil pressing plant in Lilongwe	Niqel has established 200 km of all-weather road. This allows community members from surrounding villages to access the tar road during the wet season, which was impossible in the past. Niqel is also building a new primary school and has created small dams for water provision to local communities. Niquel is also investing in an oil pressing facility.

Both projects are located in areas of predominately subsistence agriculture that exhibit high food insecurity (Table 1). However, there has not been any substantive evidence to suggest that jatropha cultivation has reduced the food crop production of the involved smallholders (BERL) or plantation workers/adjacent communities (Niqel). In the case of BERL, farmers were informed and incentivized to only convert a small portion of their farm to jatropha, usually as hedges. Income from jatropha may allow households to purchase food during the time of the year when they are the most food insecure, possibly having a positive (yet difficult to quantify) impact on food security [117] (Section 6.2). However, the size of the farm is important, with small farms potentially not being able to accommodate substantial jatropha production. Still, the competition between jatropha trees and other crops is a real concern when it comes to food security, and needs to be further investigated. Niqel, on the other hand, is located in an area of abundant land and low population density. All plantation labourers interviewed grow food crops on their small farms. Niqel only employs one labourer from any given household and the labourers reported that this re-allocation of household labour does not negatively influence food production, as they will hire extra labour if household labour is insufficient. Some respondents confirmed that the salary provided by Niqel allowed them to buy food and other household items during periods of drought having potentially a positive impact on food security [117].

Both projects have made extensive efforts to engage with local communities. Niqel undertook detailed community consultations as part of their EIA [116] and they have structured their plantation to minimise the relocation of local community members. The area finally selected for jatropha cultivation represents only a small proportion of the land originally allocated. In addition, there is a "soft" boundary between the plantation and the local communities, with the plantation literally going around farmers who chose not to be re-located. In effect, the local community has been integrated into the area of the plantation rather than being fenced off from it. Many farmers chose however to be re-located and since land is not scarce in the area, this did not seem to be an issue resented by the community. In addition, the community has benefited substantially by an improved all weather road infrastructure and shallow dams to collect water.

BERL used a network of extension staff to "sell" the benefits of jatropha to farmers. In addition, the staff assisted farmers with knowledge about jatropha cultivation and access to seedlings. BERL had also contracted seed buyers to purchase seeds directly from the grower villages. This was very beneficial for remote villages as it reduced the opportunity cost of the time invested by farmers to take the harvested seeds to centralised selling points. In this sense, it can be said that the model promoted by BERL was designed to take farmer needs into consideration.

However, a few important concerns remain for both projects. Both projects will require sufficient yields to meet the running costs of oil presses and seed-collecting activities. Long-term financial viability will probably require yields above those currently obtained. It still remains a big unknown whether sufficient yields from mature trees will be achieved in the long-term, especially since both projects used unimproved seed. In this sense, the long-term economic viability of the two projects is not guaranteed. The actual cost (Niqel) and the opportunity cost (BERL) of seed harvesting also remains a concern for both companies. Jatropha picking is labour intensive and can only therefore support low wages (for Niqel). Semi-automated dehusking could greatly reduce the labour requirements for BERL. In the BERL model, there is also a potential concern of competition between jatropha trees and other crops. This interaction needs further investigation.

We should note that due to the different demographics and farming practices in Mozambique and Malawi, the two jatropha growing models might not be interchangeable. The low population density and relatively extensive areas without smallholder crop production in the vicinity of Niqel has allowed the large jatropha plantation to avoid land disputes with the local communities. In areas of higher population density such as Malawi, this model would probably not be possible without adversely affecting existing agricultural practices. On the other hand, smallholder models based on jatropha cultivation in hedges might be possible in Mozambique. Since land is not the limiting factor of subsistence agriculture (at least in this part of Mozambique), it would also be possible for smallholders to plant jatropha in small plantations which are spatially separated from crop fields to reduce any potential negative tree-crop interactions. However, labour might end up becoming a limiting factor of production, while the logistics of collecting seeds from smallholders in remote areas of Mozambique are not to be underestimated.

Locating jatropha in climatically and edaphically suited locations is also important. Niqel is located only 60 km from the site of the Sun Biofuel's project in Chimoio (Mozambique), but their trees have performed far better. BERL, on the other hand, has planted jatropha trees (~18 million trees) throughout Malawi. It is likely that some areas will end up performing better than others. This will require further investigation once a significant number of yields have been achieved across the country. Finally, it is advisable to cultivate improved varieties of jatropha with higher (and proven) yields in future planting. The current use of "wild" seeds has resulted in a wide range of realized yields between the individual farmers interviewed in Malawi.

6. A Resilience Perspective on Jatropha Production in Southern Africa

6.1. Jatropha Systems through a Resilience Lens

One viewpoint that can be used to determine whether jatropha is a promising development option in southern Africa is to consider if it can enhance the overall resilience of the coupled social-ecological system in which it is being implemented. To our best knowledge, resilience thinking has rarely (if ever) been used to explore the impacts of different biofuel pathways. Below we consider the social-ecological system at two levels, the household level and the national level

First of all, the jatropha system must be conceptualized as a component of a complex farming system, consisting of several enterprises and elements. Jatropha farming does not occur in isolation, but forms part of the portfolio of on-farm livelihood strategies, influenced by global situations, national priorities and unforeseen circumstances. The drivers and feedbacks between the different elements of the jatropha system then need to be considered using a social-ecological systems framework [116]. The resilience of the jatropha system is thus affected by contextual factors or "givens", as well as changes in influencing variables or drivers, particularly the slow-onset variables which incrementally and cumulatively result in major and abrupt changes [118,119].

Contextual factors, which remain largely static, include abiotic factors such as substrate, geomorphology and climate; farmer characteristics; national laws and policies; and the autecology of jatropha. Jatropha's impact on other food crops and the response of its yields to droughts are not well understood. If jatropha gives good yields in drought years then it might be a good livelihood buffer against the impact of droughts on other crops. However, it is in drought years where there may be the greatest tree–crop interactions. Thus, contextual factors may be either conducive to jatropha production, marginally conducive or not conducive at all. When contextual factors are marginal, the internal resilience of the system is intrinsically low from the outset.

Dynamic influencing factors, mainly slow variables [120], include trends in ecosystem services; the capacity of provincial, local and national government departments and the private sector to engage with local communities; trends in public infrastructure; the cost of labour; knowledge and skills in jatropha production; and population density which influences land availability and thus the opportunity cost of land. All these elements are influenced by trends and processes at the national and the global scale as they interact with local processes. These include the global demand for biofuel, total national and global biofuel supply, and input costs such as fertilizers and implements.

The above factors interact through feedbacks and are characterized by thresholds or "tipping points" [121] which, if crossed, may result in regime shifts [119] from one state to another [122]. Several thresholds might be crossed simultaneously, leading to cascading regime shifts with long-term yet undesirable consequences [123]. Jatropha project collapses can be seen as such regime shifts with undesirable consequences. However, successfully implementing biofuel production may move the system to a new state with enhanced social benefits.

Other factors that may influence the general resilience of jatropha systems include:

- The diversity of livelihood strategies and farming enterprises, at the household and the village scale. At the household level, adding jatropha to a smallholders' crop portfolio means that the farmer diversifies income sources;
- The level of initial investment in jatropha, influenced by the expectations of yields and profits, may increase or decrease resilience. In cases where profits were over-estimated, initial investments resulted in a "gilded trap" [124,125];
- The flexibility in labour arrangements, e.g., households' ability to hire people to supplement on-farm labour;
- The availability of cash reserves. This may buffer the system against economic collapse during the initial enterprise development stages and during dry years;
- The willingness and capacity of stakeholders to learn, reflect, innovate and adapt.

The last factor is central to resilience building [126] and is therefore essential for building trust and mutual respect amongst stakeholders, especially during the early stages of jatropha implementation. It is also essential for implementing a system of adaptive management, which includes monitoring systems, agreements on thresholds of potential change (and actions to be taken when these are crossed), as well as administrative processes that tolerate (and preferably encourage) adaptation and innovation [127].

6.2. Can Jatropha Increase Resilience in Southern Africa?

In light of the discussion in Section 6.1 and the operational characteristics identified in Section 5, jatropha can potentially increase the resilience of (a) local communities to livelihood shocks; and (b) national economies to energy supply shocks.

Regarding household-level resilience, jatropha cultivation in Malawi was found to give farmers cash income (that was nevertheless admittedly low) during a period of the year when they had no other crop to consume or sell. Our rough calculations suggest that a day's picking and preparing 8 kg of jatropha seeds could offer enough income to purchase 9 kg of maize which could feed an average household for 3.4 days. As such, jatropha should add to the overall diversity, and thus resilience, of household livelihood strategies. Our data from Mozambique suggest that the salaries of plantation workers represented a substantive increase in cash income for local households and were a safety net in times of drought when there was a reduction in food crop yields [117]. Furthermore, the ability to hire paid labour for the cultivation of family farms resulted in little or no impact on the overall food-producing ability of households that diverted labour for paid work in plantations.

At the national level, the fuel produced by both BERL and Niqel could potentially enhance resilience against energy supply shocks. Niqel might contribute about 1.5% of national diesel needs, whilst BERL's long-term ambition is to achieve a national 9% jatropha biodiesel blend. In both cases, this domestically produced fuel can reduce reliance to imported fuel (Section 3.1), thus providing a buffer against fuel price volatility. At the same time, it can improve trade balance as liquid fuels are imported. Achieving these resilience benefits in Malawi will greatly depend on long-term jatropha yields as well as the level of jatropha uptake among smallholders.

We have to note that in order to provide the local and national resilience benefits speculated above, both projects have to remain economically viable. Even though there are some positive signs (Section 5), this is by no means ensured as witnessed by the mass collapse of jatropha projects in the region (Section 4.2).

7. Conclusions

Though we fully realize that the drivers, historical evolution, operational characteristics, reasons for success/failure and impact of the jatropha projects discussed in this paper are context-specific, not the least due to unique national characteristics, still some overarching trends can be identified.

A key feature of the jatropha hype was the large-scale and zealous promotion of jatropha based on unproven claims and selective use of available data. This led to the rapid uptake of jatropha that was, to a large extent, further facilitated by an environment that was, at that stage, very receptive to the concept of a new biofuel crop for southern African.

In particular, the lack of sound research prior to the wide-scale promotion of jatropha did not allow for the correct understanding of the plant's local climatic and agroecological constraints. This was clearly a key reason for its later collapse in the region. Grossly overestimated and unrealistic yield expectations in several cases derailed the financial planning of the companies that undertook jatropha growing. In hindsight, extended local field trials conducted under plantation conditions would have been an important first step to build a solid knowledge basis to guide the subsequent expansion of the crop. Equally, the timing of the 2008 financial crisis forced investors to withdraw money, while the sudden decline of oil prices in 2008 reduced the profitability of jatropha-based fuels. Though this was probably not the core reason for the collapse of jatropha, it certainly added to the rapidity of the collapse. Usually R&D and extension activities were the first to be cut, greatly limiting the potential to build the needed knowledge basis.

Jatropha is unlikely to expand to the extent initially predicted in southern Africa. Currently, a relatively small proportion of land is being planted with jatropha, as most projects have not expanded to the full extent specified in their leases. However, whether jatropha will find a niche as a useful crop in southern Africa is yet to be determined. A starting point is the wild varieties currently grown in southern Africa, which do not produce the high yields that were anticipated. It is possible that plant breeding may partly resolve this problem and result in high-yielding jatropha varieties. Results from jatropha breeding programmes have only just started to become available and were not used at all in the early southern African projects. It should also be noted that the main cash crops in the region have gone through hundreds of years of genetic improvement, something that was never the case with jatropha anywhere in the world.

Considering the above it seems safe to infer that contrary to what was initially speculated, jatropha is unlikely to become the high-value crop that would bring huge cash flows into rural areas. More likely, jatropha can support a reasonable number of labourers at a rate equal to (or slightly better than) the minimum wage in most countries of southern Africa countries, with a few better-paid specialist and managerial jobs. For small-scale farmers, jatropha can supplement and diversify farm income, rather than becoming a high-value cash crop in its own right. In our view, jatropha is likely to remain a relatively low-value crop due to the high labour requirements for seed picking and dehusking. Unlike many other oilseed crops, the low value of the seedcake (due to its toxicity) reduces jatropha's overall profitability by limiting the utilization of what could be a more valuable by-product.

Yet, while most jatropha projects in southern Africa have collapsed, a few still operate (e.g., BERL Malawi, Niqel Mozambique). This would appear to be in cases where jatropha is climatically suited, yield expectations are low, sound economic planning has been undertaken, management is good, markets are secured and there is sensitivity to local social issues. Both small-scale and large-scale models may work, with small-scale projects being more suited to areas of high population density, and large-scale projects more appropriate to areas of land abundance. We cannot stress enough though, that the viability of these projects is not guaranteed and jatropha needs to be considered as a high-risk crop until proven otherwise.

Integrating jatropha into the southern Africa agricultural landscape can possibly increase resilience at the household (to livelihood shocks) and at the national level (to energy supply shocks). Jatropha can offer an additional income stream to smallholders and workers in plantations. This income can be especially important if jatropha harvests/income come at times when there are no other food crops to consume or cash crops to sell (due to cropping calendar or following drought-related events). Growing jatropha in modest amounts might have noticeable impacts on fuel security and foreign exchange expenditure particularly in landlocked poor countries of southern Africa in times of high-energy market volatility. In any case, these resilience benefits are contingent to jatropha growing being a financially viable venture for the companies that undertake it or promote it.

Finally, governments in southern African clearly had an important role during the jatropha hype and its aftermath. Governments seem to have been a victim of the jatropha hype accepting a series of unsubstantiated claims at face value. At the same time, ineffective government involvement might have affected the viability of some jatropha projects and at the same time failed to safeguard the land rights of local communities. Some learning points would be that governments must either conduct (or demand from the industry) agronomic trials before allowing new crop introduction, including jatropha.

Furthermore, governments need to provide incentives for the development of proper markets and better protect local communities by ensuring that they (or their land) are not exploited. This means that governments in southern Africa have a fine balance to strike between attracting investments and at the same time ensuring the costs and benefits of jatropha production are justly distributed.

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Author Contributions

Graham von Maltitz and Alex Gasparatos jointly undertook the field research whilst Christo Fabricius, developed the resilience concepts. Graham von Maltitz was largely responsible for analyzing the field data. All authors contributed to development of the final report.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

1. For the purpose of this paper we consider southern Africa as the area comprising of Botswana, Lesotho, Namibia, Madagascar, Malawi, Mozambique, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe.
2. “Miracle” or “wonder” crops are interchangeable terms loosely used in the literature to describe crops that are promoted due to their perceived disproportionately high benefits. These terms are often used in a slightly disparaging manner from those who consider such crops to be over-promoted based on unrealistic claims. For jatropha, this term is encountered both in its literal positive sense or a sarcastic sense questioning jatropha’s potential to offer the perceived benefits.
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