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Article

Jatropha Developments in Mozambique: Analysis of Structural Conditions Influencing Niche-Regime Interactions

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Abstract: This article investigates the transition dynamics related to Jatropha developments in Mozambique. The analysis focuses on how structural conditions (infrastructure, institutions, interaction and collaboration and capabilities and resources) enable or constrain interactions between niche-level Jatropha experiments and incumbent energy, agriculture and rural development regimes in Mozambique. Investors in agro-industrial Jatropha projects focused on establishing projects in areas with relatively good infrastructure, rather than in remote rural areas. Furthermore, they predominantly focused on Jatropha production instead of investing in the entire Jatropha value chain, which turned out to be a challenge in itself, as growing a productive Jatropha crop was much more complex than initially anticipated. The development of institutions that could nurture and protect Jatropha projects from the prevailing regimes lagged behind Jatropha project establishment, leading to an insecure investment climate. Strong inter-ministerial collaboration and organized civil society interaction and representation contrasted with non-organized private sector and rather isolated smallholder Jatropha projects. The global financial crisis and limited adaptive capacity reduced the time and space for experimentation and learning to overcome disappointing crop performance. Together, this hampered Jatropha's potential to challenge the energy, agricultural and rural development regimes. Nevertheless, the Jatropha experience did initiate the development of policy and regulation and stimulated interaction and collaboration between specific groups of stakeholders, which could provide the basis to capture future biofuel momentum in Mozambique.

Keywords: bioenergy; biodiesel; system innovation; Sub-Saharan Africa; policy; agricultural innovation; value chain; adaptive capacity

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1. Introduction

The worldwide interest in biofuels has been triggered by several threats and opportunities. The first threat is the rapid depletion of fossil fuel reserves leading to high fuel prices that are pressuring national and household budgets. Second, fossil fuel reserves are not equally distributed across the world, and their supply is often irregular, leading to political and economic dependencies and instabilities. Third, greenhouse gas (GHG) emissions resulting from the combustion of fossil fuels form one of the main drivers of global climate change and the negative environmental, social and economic consequences associated with that. Opportunities include the emergence of new markets for existing (maize, cassava, sugarcane, oil palm, soybean) or new (Jatropha, castor, rapeseed) biofuel crops for farmers in both the developed [1] and developing world [2]. An additional opportunity is the production of energy at the national or subnational level, reducing the costs and dependency related to fossil fuel imports. Several governments, especially of fossil fuel importing developing countries, have advocated such decentralized domestic energy production as (1) an engine of national and local economic development and (2) a way to generate foreign exchange by supplying the international biofuel market.

Mozambique is one of the many developing countries that engaged in producing biofuel feedstock for the domestic, as well as for the international biofuel markets, mainly the European Union (EU). One of the new biofuel crops that was promoted by the Mozambican government was *Jatropha curcas* Linnaeus (henceforth abbreviated as Jatropha). Jatropha is a small tree or shrub that produces toxic grain with a relatively high oil content of between 30% and 35% [3–5]. It was generally assumed that Jatropha could foster national and local energy production, enhance agricultural productivity through private sector investment and the transfer of technology in the agricultural sector and facilitate rural development through the creation of employment and infrastructure in rural areas [6]. Despite the promotion of, initial enthusiasm for and huge investments in Jatropha by the Mozambican government, development organizations and the private sector, the crop did not achieve its potential in terms of fostering a change of energy, agriculture and rural development regimes in Mozambique.

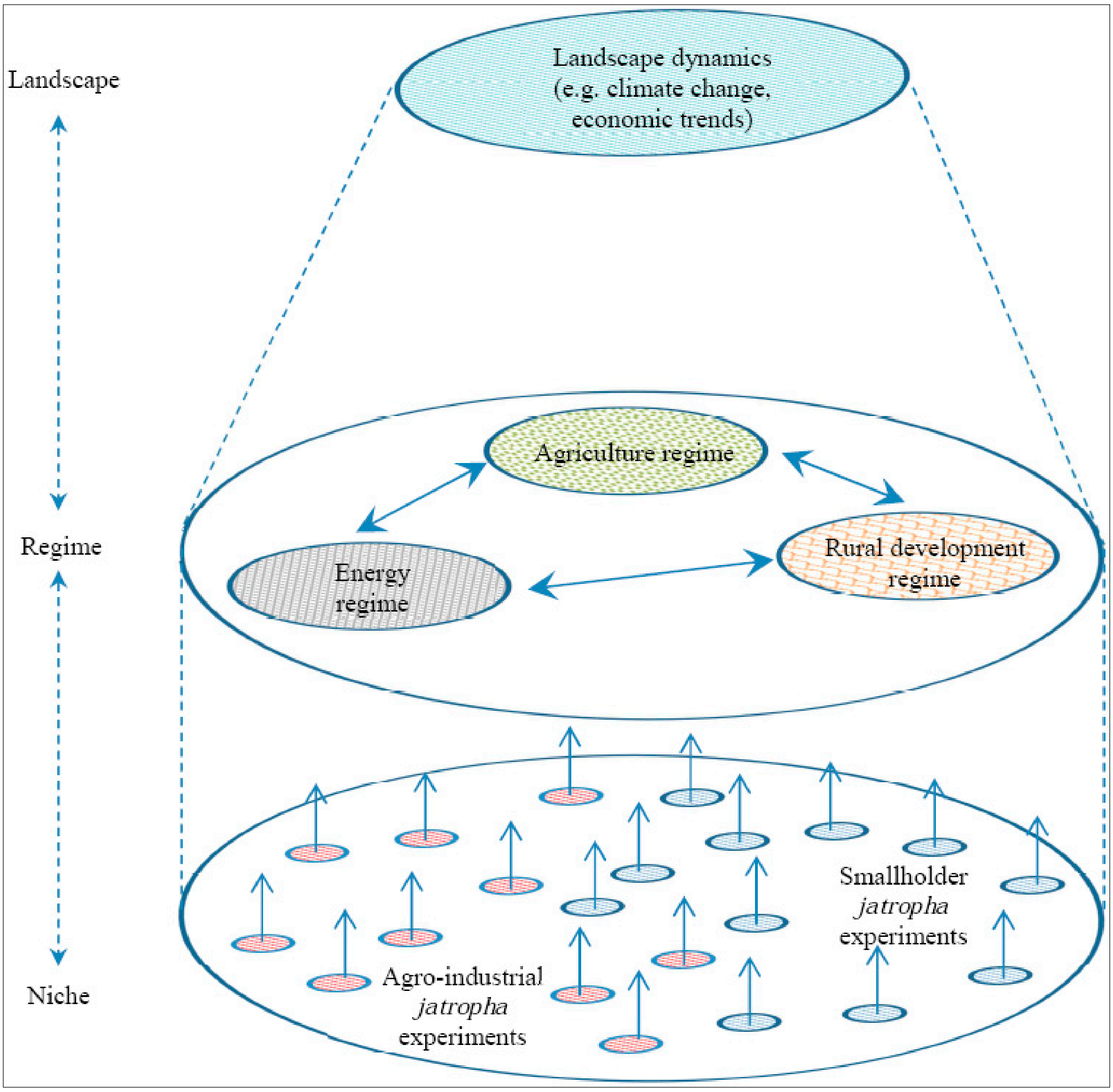
In this paper, we study Jatropha developments in Mozambique using niche-regime-landscape theory (also referred to as transition theory or a multi-level perspective on socio-technological transitions) developed by Geels [7]. We describe and analyze niche-level Jatropha projects and how they interact with the evolving energy, agriculture and rural development regimes. Although the main focus is on analyzing niche-regime interactions, the impact of changes at the landscape level will be discussed to some extent. The objective of this paper is to better understand the structural conditions that influence niche-regime interactions and how these enabled and constrained Jatropha developments in Mozambique. Our paper builds on the work of colleagues that have applied niche-regime-landscape theory to analyze prospects and evolutions of Jatropha biofuel developments in other developing countries, such as Tanzania [5,8]. By integrating the analysis of the rural development regime, we complement existing studies applying a multi-regime perspective, as these mainly focus on analyzing energy, agriculture and transport regimes (e.g., [9]). Including the rural development regime is crucial, as this is a key objective for promoting biofuels in many developing countries [2].

2. Conceptual Framework and Research Approach

Transition theory states that numerous niche experiments are needed to support regime changes, which, in turn, interact with landscape dynamics. Landscape is the broad overarching and societal context within which regimes and niches are embedded. Landscape dynamics go beyond a particular sector of economic activity, for example climatic trends, economic growth trends or political environments. Despite their external character, landscapes can and do change, to some degree influenced by regime changes [10]. However, landscape changes have much longer time horizons than regime changes [7]. Regimes have been described as the "dominant way of doing things" in a particular sector or economic activity [8]. A regime represents the prevailing selection environment for innovations that is embedded in formal (rules and legislation) and informal (culture, norms, practices) institutions [10]. Consequently, regimes can exert path dependencies and barriers for innovations to succeed and diffuse [11]. Niches are temporary socio-technical spaces in which (radical) innovations can emerge and mature through experimentation and learning [5]. Niches can shield and nurture innovations from the prevailing technological (effectiveness) and market (competitiveness) pressures imposed by regimes. Space for niche-level innovations can emerge from tensions at the regime level, for example, when the "dominant way of doing things" no longer satisfies the needs, interests and objectives of (a subset of) regime actors. Regimes can also deliberately create space for niche-level innovations, for example through innovation policies or subsidies. However, these types of innovations are often incremental rather than radical [7].

In this article, we investigate the transition dynamics related to Jatropha in Mozambique. Our analysis focuses on how niche-level Jatropha experiments in Mozambique interact with incumbent energy, agriculture and rural development regimes. Although we believe that changes within these regimes could ultimately contribute to a transition towards a more bio-based economy, this aspect is beyond the scope of this paper (Figure 1). At the niche level, we subdivide between agro-industrial and smallholder Jatropha experiments. The first category includes projects and plantations where Jatropha was mainly planted in monocultures and for export to key biofuel markets (mainly the EU). The second category includes government- and NGO-supported Jatropha projects with smallholder farmers and communities aiming to locally generate energy (pure plant oil for lamps, for stoves or for a generator) or to generate additional income by selling Jatropha seeds to plantations. The two categories have different objectives and characteristics, but both interact with prevailing regimes, as well as with each other at the niche level (e.g., competition between different projects). Consequently, we believe that both need to be analyzed to understand how niche-regime interactions influenced Jatropha developments in Mozambique.

Figure 1. Landscape, regime and niche interactions for Jatropha (adapted from [7]).



Niches, regimes, landscapes and their interactions are not static, but evolving. In the case of biofuels and more specifically Jatropha developments in Mozambique, the beginning of a transition process emerged when several landscape factors started to converge. For example, perceived high fossil fuel prices and dependency, climate change problems and opportunities for agriculture and rural development fostered the initial promotion of and investments in biofuels. This, to some extent, destabilized and pressurized existing energy, agriculture and rural development regimes and created opportunities for innovation in these regimes.

Several scholars have linked transition theory to (system) innovation theory. Leeuwis, for example, defines innovation as the co-evolving process of technological (e.g., cultivars, fertilizer, agronomic practices) and socio-organizational (e.g., institutional settings, such as land-tenure arrangements) changes and analyzes how investments, rules, actor-networks, norms, competencies and worldviews embedded in prevailing socio-organizational and technological regimes influence the extent to which innovations diffuse beyond the niche-level ([12]; see also [10]). Klein Woolthuis and colleagues identified four categories of structural conditions responsible for system failure (Table 1) ([13]; see also [14,15]).

Table 1. Structural conditions that can enable or constrain niche-regime interactions (based on [13,15,16]).

Structural Conditions	Description and (Biofuel-Related) Examples
Infrastructure	Knowledge infrastructure (research; agricultural extension services); physical infrastructure (roads, harbors, irrigation, fuel storage or processing facilities, agricultural input supply)
Institutions	Formal institutions (energy, agriculture and rural development policies, subsidies, tax breaks, market (access), trade agreements); informal institutions (behavioral patterns, cultural norms, values, trust)
Interactions and collaboration	Multi-stakeholder interactions, learning for problem-solving; development and sharing of knowledge and information; partnerships; networks
Capabilities and resources	Competences; flexibility and adaptive capacity; financial and human resources; education; entrepreneurship

These structural conditions exist at the niche and regime level and, in our opinion, can constrain and enable niche-regime interactions in different ways. First, existing infrastructure (e.g., the fossil fuel distribution network in the transport sector), institutions (e.g., fossil fuel subsidies), collaborations and interactions (e.g., between fossil fuel exporting and importing countries) and capacities and resources (e.g., mechanical knowledge of fossil fuel cars) can constrain niche-level innovations (e.g., electric cars) from achieving change at the regime level. Second, these existing structural conditions can also enable niche-level innovations in initiating changes at the regime level. For example, existing liquid fossil fuel storage and distribution infrastructure may also be used for alternative liquid biofuels. Third, newly established structural conditions can increase the likelihood that niche-level innovations will lead to changes at the regime level. For example, the establishment of a multi-stakeholder platform around biofuels can stimulate interaction and collaboration and strengthen the capacity development and mobilization of resources to protect, nurture or strengthen innovations. In our reflection of Jatropha developments in Mozambique, the structural conditions and the different ways in which they can constrain and enable innovation guide our analysis of interactions between the niche-level Jatropha projects and the incumbent energy, agriculture and rural development regimes.

Data for this study was gathered between 2008 and 2014. During these six years, research conducted by 20 MSc students, four PhD students and a junior researcher from Wageningen University provided a broad variety of qualitative and quantitative data on the potential for Jatropha in Mozambique, the performance of individual agro-industrial and smallholder Jatropha projects, the impact of biofuel projects on the environment, economy and society and the development of the Mozambican policy framework for sustainable biofuels. As part of these studies, the majority of Jatropha projects in Mozambique were visited, and different types of stakeholders, including policymakers, farm households, investors, plantation managers, civil society representatives and other researchers, were interviewed. Secondary data analysis includes the analysis of Jatropha project investment proposals, Mozambican policy documents, newspaper articles, press releases and presentations made by investors, policy makers or researchers. Furthermore, we used the analysis of five agro-industrial Jatropha projects in Mozambique that was conducted in the scope of the “Netherlands programme for sustainable biomass” funded by the Dutch government [17].

3. Interactions between Niche-Level Jatropha Projects and Energy, Agriculture and Rural Development Regimes in Mozambique

Mozambique is an attractive country for biofuel investors. It has large stretches of uncultivated land, and it has a relative friendly investment environment for foreign companies [18–20]. Furthermore, the climate is suitable for high potential yields of most bioenergy crops [19], and labor is abundantly available [20]. Mozambique is a signatory to several trade agreements that establish the terms and conditions for (duty-free) access to Mozambican biofuels by key regional and international markets, such as the Southern African Development Community (SADC), the EU and the United States [21].

Despite its biofuel potential, the production of biomass for biofuels in Mozambique is controversial, as one third of the population is chronically food-insecure and half a million children aged 6–23 months are undernourished [22]. During the presidential election campaign in 2004, the Mozambican government encouraged farmers to produce Jatropha on all unused, marginal soils, so that Mozambique could become an oil exporting country instead of being fully dependent on oil imports. As part of the campaign, the president stated that each of Mozambique's districts had to plant 5 ha of Jatropha, using marginal land to avoid competition with food production [21]. Jatropha was promoted as an opportunity for smallholder farmers and as a crop that was easy to cultivate. Although the promotion of Jatropha by the Mozambican government had mainly focused on smallholders and communities, it also attracted investors with interest in planting this biofuel crop on agro-industrial plantations.

3.1. Niche-Level Jatropha *Projects and Their Interactions with the Energy Regime*

The main sources of energy in Mozambique are fuel wood and charcoal, liquid fossil fuels (gasoline and petroleum), natural gas and hydroelectricity, of which the majority is directly exported to South Africa and Zimbabwe. Approximately 11% of the population had access to electricity in 2008 [18]. Electrification efforts mainly concentrate on urban areas and important industrial zones, such as the Maputo and Beira (fuel) corridors [23]. About 70% of the population depends on fuel wood or charcoal, including urban households. The majority of oil products are imported and accounted for an increasing share of total imports: 10% in 1997, 15% in 2006 and 17% in 2007 [24]. The storing capacity of fossil fuels is limited, mainly in harbors and in the fuel corridors, which makes Mozambique dependent on foreign oil markets and sensitive to fluctuations in oil prices [18]. Mozambique is an important transit country for land-locked fuel importing countries, such as Zimbabwe and Malawi. The consumption of oil products increases with urbanization and economic development. Stable and affordable access to fuel is crucial for political stability in Mozambique. When the Mozambican government announced a reduction of fuel price subsidies in 2010, citizens protested and rioted [25].

In response to the huge interest by investors, the Mozambican government developed a National Biofuels Policy and Strategy (NBPS). The NBPS was published in May, 2009, and explicitly mentions sugarcane, sweet sorghum, Jatropha and coconut as the approved biofuel crops. Through the implementation of the NBPS, the Mozambican government aimed to contribute to energy security and diversification of the energy matrix by exploiting agro-energetic resources [6]. Another important reason for promoting biofuel and Jatropha production was to reduce its expenditure on fuel imports by creating a domestic market for Mozambican biofuels and to increase exports to generate tax revenues and foreign currency [6,26]. Concrete targets were biomass for biofuel production on 450,000 ha, compulsory blending of 10% bioethanol with gasoline and 5% of biodiesel with fossil diesel, leading to a reduction of oil imports and the creation of 150,000 jobs [6].

In terms of fulfilling the energy regime change, both failures and successes are reported. In 2011, one of the agro-industrial projects delivered Jatropha oil to a German airline from seeds produced and pressed in Mozambique [27]. This event was presented as proof that Jatropha production in Mozambique had a bright future and was worthwhile to invest in. Between 2007 and 2011, agro-industrial plantations did not contribute to the diversification of the Mozambican energy matrix. Jatropha seed production per hectare was low and there was no operational domestic market due to a lack of processing infrastructure and a lack of blending regulation.

Several smallholder Jatropha projects were initiated following the presidential campaign of 2004. Projects aimed to generate oil for lighting, for soap production or for application in generators to produce energy. Although some projects had an oil press provided by the government, insufficient oil was produced due to low Jatropha seed production. One particular smallholder Jatropha project aimed at growing the equivalent of 250 to 500 hectares of Jatropha in hedges around fields, which farmers preferred over planting Jatropha in fields as monoculture. The objective of this project was to build a viable oil processing facility and to adapt diesel engines already in use for operation to pure plant oil [28]. The choice of modifying the engines to run on Jatropha oil instead of producing biodiesel was based on the desire to keep technical complexity to a minimum. To compete with local kerosene and diesel prices, the price of Jatropha seed remained unattractive for smallholder producers, also because Jatropha yields remained very poor. During later stages, experiments with biogas production from Jatropha press cake were foreseen, although by then, many Jatropha producers had abandoned the crop. In general, smallholder Jatropha projects did not fulfil their potential in terms of contributing to local energy self-sufficiency.

In November, 2011, the Biofuels Blending Regulation was approved, establishing a gradual mandatory blending of 3% biodiesel with fossil diesel and of 10% bio-ethanol with gasoline from 2012 onwards [29]. Under the regulation, export of biofuels is only allowed after assuring domestic biofuel requirements. The blending target for biodiesel had been reduced to 3% as compared to the anticipated blending target of 5% that was included in the NBPS. However, the disappointing yields of Jatropha plantations resulted in an insufficient produce to even meet the lower 3% target. Despite this, several investors remained optimistic. For instance, Cuvilas and colleagues reported that the biggest Mozambican oil company projected producing 226 million L of Jatropha biodiesel [18]. The project would be implemented in three phases, creating 800 jobs and reducing the country's fossil fuel import.

From 2011 onwards, the discovery of natural gas and coal overshadowed investments in biofuels in Mozambique [30]. Furthermore, the Mozambican government's commitment to finalizing and approving biofuel-related policies has stagnated. For example, the policy framework for sustainable biofuels, which is supposed to guide sustainable biofuel investments in Mozambique and which was finalized in July, 2012, was still to be formally approved and implemented by the Mozambican government at the time this paper was published [26].

3.2. Niche-Level Jatropha *Projects and Their Interactions with the Agriculture Regime*

Agricultural census data from 2008 [31], which provided the basis for Mozambique's agricultural policy [32], demonstrate that 2.7 million smallholder farmers are responsible for 95% of the agricultural production; mainly food crops. Agriculture occupies about 80% of the national labor force. Smallholders are characterized by land areas smaller than 3 ha, the predominant use of family labor and the low use of inputs, such as improved seed (10% in case of maize), chemical fertilizer (5%) and animal traction (11%). Approximately 8% of smallholder farmers have access to extension services, and 7% of them are organized in informal non-registered farmer associations. The average yield of maize, the main staple crop, is 1 t/ha [25], although this can be much lower for less resource endowed farmers [33]. Although access to agricultural land is generally not a problem, smallholders suffer from labor constraints and a lack of inputs lead to shifting cultivation on small plots [34]. In contrast, Mozambique has a long tradition of commercially cultivating large-scale irrigated sugarcane for sugar. Although many plantations were not well maintained, the option of producing bioethanol revived interest in and even led to the establishment of new sugarcane plantations.

During the 2004 election campaign, the Mozambican government could not provide good quality Jatropha seed to smallholders [21]. Most of the seeds were sourced from Malawi and were of poor quality, showing low germination rates [35]. After distribution of the seed, support for farmers in terms of providing knowledge on the production of Jatropha hampered. As a result, crop maintenance was neglected and many plants died. The few Jatropha seeds produced remained in their production sites, due to lack of organized markets and supply chains. In many parts of the country, smallholder Jatropha projects experienced pest, disease and management problems. Some projects relocated themselves to areas with less pest and disease pressure, while others collapsed as farmers lost confidence in Jatropha [33]. Slowly, government officials and NGOs that had promoted Jatropha as an "easy to cultivate" biofuel crop for smallholders started to realize that development of Jatropha was far more complex than was initially anticipated [36].

During a scientific biofuels conference, held at Eduardo Mondlane University (UEM) in September, 2009, Jatropha-related presentations dominated over half of the contributions [37]. Presentations by representatives of agro-industrial projects confirmed problems with Jatropha, including pests and diseases, seed origin and poor germination. Discussions revealed that agro-industrial projects realized that the Jatropha *s*ector would only take off if sufficient volume would be produced, and data resulting from on-plantation agronomic experiments were shared among the different plantation managers and other researchers. Variety trials were not shared and considered essential components of companies' capital and competitive advantage. Furthermore, breeding programs were not undertaken, as they are costly long-term investments, especially for perennial crops, that go beyond the investors' time horizons for returns on investments.

On plantations and in smallholder projects, research and internships by students were welcomed as a means to "hire" cheap scientific labor, as a means to evaluate current practices, to get access to other scientific findings and as input for improving management practices. Several students were offered jobs in biofuel projects after finishing their studies. Within the UEM most Jatropha research was part of the forestry department. This research focused on policies related to forestry (e.g., potential for claiming carbon credits for Jatropha planting) and wood production (e.g., [38–40]), instead of on more agronomic research on factors influencing Jatropha seed production. Furthermore, research activities focused on emergent and urgent problems, such as on Jatropha pest and disease control (e.g., [41]).

The NBPS commissioned a land zoning exercise needed to underpin assessments of bioenergy and other investment proposals and allocate land titles [21]. Furthermore, this would provide information on the availability of land and the suitability of that land for specific crops. The delayed outcome of the exercise contributed to the establishment of plantations in undesired areas and land clearing activities being undertaken without the required permits [26]. The NBPS also aimed at stimulating technology transfer, *i.e.*, spillover effects from technology for biofuel production to food production [6]. Research presented during the biofuels conference at UEM reported on competition with food production by smallholders, distinguishing between on-farm Jatropha production potentially replacing food crop production and off-farm labor in Jatropha plantations potentially decreasing the time available for on-farm food production [42]. However, off-farm labor allocation would also lead to increasing smallholders' income and, thereby, their access to food. An evaluation of five Jatropha plantations showed that plantation workers decreased time spent on home food production, and consequently, they perceived that their food security situation had decreased, whereas others perceived that their food security situation had improved as they could buy food [17]. One agro-industrial Jatropha project was found to have invested in on-plantation food production to provide food to its workers against cost price or even for free [43]. Meanwhile, the production of Jatropha in the majority of smallholder and agro-industrial projects largely failed, due to a lack of knowledge regarding seed varieties, good agronomic practices, production systems, markets and the scale of operations. Technology spillover effects from agro-industrial Jatropha projects to food production by smallholders were very limited, as Jatropha plantations generally invested little into improving smallholders' home food production through the provision of agricultural inputs or technical assistance.

In 2012, the center for agricultural investment promotion (CEPAGRI) monitored six agro-industrial Jatropha projects for the production of raw materials for biofuels [44]. They observed that due to the limited technical and agronomic knowledge available about commercial production of Jatropha, projects were embarking on a simultaneous process of planting and investigation. However, production levels remained low, below 500–600 kg/ha (according to [44,17], respectively). This demonstrated a significant gap when compared to the projected yields of 2640 kg/ha, as aimed for in project investment proposals that were submitted to the Mozambican government up to December, 2008 [21]. As a consequence, income per unit of land and labor was low, which made the overall financial profitability and viability of Jatropha production within both smallholders and agro-industrial projects questionable, as compared to investments in other cash or food crops. CEPAGRI also reported that despite ambitious plans, no investor seemed capable of clearing and planting Jatropha on more than 1000 ha per year (in reality, between 350 and 800 ha/year). As a result of the uncertainties regarding commercial production levels, many of the agro-industrial Jatropha projects were unable to develop credible business plans to attract new investors and financing for the realization of these projects. Van Eijck and colleagues concluded that due to high investment costs, the low development rate of plantations and low yields, the production of Jatropha oil is too expensive to compete with palm oil or fossil fuel; hence, production of Jatropha oil is not a business proposition in the near future [17]. As a consequence, many of the agro-industrial Jatropha projects faced financial problems or went bankrupt [26]. CEPAGRI concluded that only those projects that have linkages with international companies in the fuel sector are demonstrating a strong commitment to the continuation of research for the identification of better seed varieties for agro-industrial production. In 2012, several of the agro-industrial Jatropha projects moved to food production to assure the economic viability of the plantation while continuing research on Jatropha varieties [44].

3.3. Niche-Level Jatropha Projects and Their Interactions with the Rural Development Regime

Mozambique achieved an average annual rate of economic growth of 8% between 1996 and 2006, and of 6%–7% between 2006 and 2011 [25]. Per capita GDP increased from 475 to 1200 USD between 2000 and 2012. Rural development is heavily constrained by low labor and land productivity in the agricultural sector and lack of (employment) opportunities outside agriculture. Infrastructure in terms of schools, hospitals, roads, input and output markets, credit facilities and technical services is very poor. For 2007, adult literacy rates were around 44% for the population of 15 years and above, which had increased to 56% in 2013 [25]. In 2013, 83% of the population had no access to improved sanitation [25]. Lack of access to affordable fossil energy sources limits possibilities for agricultural mechanization, local processing of agricultural produce and transport of produce beyond local markets. This contributes to a lack of value addition to agricultural produce and the export of raw materials only.

An important reason for the Mozambican government to promote biofuels was to contribute to the wellbeing of the population and promote socio-economic development, particularly in rural areas [6]. During a presentation in Brussels in 2007, the Mozambican Minister of Energy underlined the government's ambition. He explained that biofuels can contribute to the national poverty alleviation agenda by creating employment opportunities for Mozambique's labor force in producing biofuels feedstock; "in particular Jatropha". He also explained that Jatropha provides "our rural population with an opportunity to generate income out of a land that did not produce anything at all, without threatening food production and food security" [20].

In practice, the contribution of both smallholder and agro-industrial biofuel projects to rural development turned out to be disappointing. Smallholder Jatropha projects initially raised high expectations, and in several projects, communal trials were established. In some cases, Jatropha was introduced within a business model for selling carbon credits generated through smallholder engagement in conservation and reforestation activities (including Jatropha planting). In other cases, the focus was on producing oil for soap production, lighting or application in a generator, whereas by-products could be used as fertilizer. These projects attracted a lot of political and media attention, which contributed to the overall enthusiasm about Jatropha. In one of the carbon credit projects, the initial communal trials and payment of farmers planting Jatropha attracted the interest of around 250 farmers from the area to plant Jatropha on their private and communal land. An evaluation study that was carried out three years later, however, showed that the communal trials were abandoned and that only a few of the individual farmers were still growing Jatropha [45]. The formerly interested farmers described Jatropha as difficult to grow and a crop for which they needed to have knowledge on pruning and virus and pest management. The evaluators concluded that it would be unlikely that subsistence farmers would allocate their scarce resources to non-edible crops of which they have little agronomic knowledge, and both yields, as well as markets were uncertain. Jatropha means a large risk to farmers who meanwhile also lost trust in the crop [33].

The majority of planned or operational biofuel projects were located in areas, where prime agricultural land, skilled labor and physical, communication and financial infrastructure was available, and not in remote rural areas, as was desired by the Mozambican government [21]. The government tried to stimulate investors to locate themselves in remote rural areas by providing tax incentives, applying the Code of Fiscal Benefits. Nonetheless, instead of investing in infrastructure, these projects sought to benefit from existing infrastructure in regions, such as in the Maputo and Beira fuel corridors, where pressure on land was already high. In some cases, this resulted in disputes with local communities on land rights and employment conditions. Interviewed investors claimed that their businesses would not be able to generate profits when located in remote rural areas and would go bankrupt before actually producing biofuels. As all land in Mozambique belongs to the state and can be leased for a period up till 99 years, land prices did not provide an incentive for investors to locate themselves in remote rural areas where land prices would normally be lower than in developed or more urbanized areas.

Actual infrastructure and employment creation by agro-industrial projects was below expectation. Between 2008 and 2013, CEPAGRI registered 38 proposals for agro-industrial biofuel projects totaling an area applied for of 407,802 hectares (Table 2). Especially between 2008 and 2011, a decline in the proportion of biofuel proposals in relation to other agricultural investment proposals can be observed, as well as the total land area applied for. During these years, many of the Jatropha companies in Mozambique went bankrupt, leaving behind cleared prime agricultural land and unemployed laborers, who, in some cases, had given up or downscaled food production on their own farms [18,44]. By the end of 2011, a total of 36 biofuel investment proposals had been received by the Mozambican government, of which 10 had been formally approved [46]. Of the requested 411,000 ha, only 8512 ha (2.1%) were actually planted. Of the projected 148,225 jobs, only 853 permanent jobs (0.6%) had actually been created by biofuel investments as of 2012 [47].

Table 2. Number and area of biofuel investment proposals related to total investment proposals from 2008–2012 [44].

Year	2008	2009	2010	2011	2012
Number of biofuels proposals	13	6	7	10	4
Total number of proposals	17	13	38	42	47
Proportion of biofuel proposals in relation to the total number of proposals	76%	46%	18%	24%	9%
Area applied for biofuels proposals in ha	191,053	65,906	49,498	93,490	54,808

4. Analysis and Discussion

Although we have described the interactions between niche-level Jatropha projects and the three regimes in a rather isolated manner, they are intertwined and influence each other. For example, the agronomic problems related to Jatropha production in smallholder and agro-industrial projects (agricultural niche-regime interactions) have to a large extent determined the ability of Jatropha niche projects to influence incumbent energy and rural development regimes. Some landscape features also played a role, such as the high, unpredictable and volatile oil prices on the world markets, putting pressure on the existing energy regime. Another example is the financial crisis, starting in 2008, reducing the availability of funding for biofuel innovations. Our analysis is shaped along the four structural conditions that can constrain and enable interactions between the niche-level Jatropha projects and the incumbent energy, agriculture and rural development regimes (Table 3).

Table 3. Examples of the structural conditions that can constrain (when absent or malfunctioning (−)) or enable (when present (+)) interactions between the niche-level Jatropha projects and the incumbent energy, agriculture and rural development regimes.

	Energy Niche-Regime Interactions	**Agricultural Niche-Regime Interactions**	**Rural Development Niche-Regime Interactions**
Infrastructure	+ Fuel infrastructure exist in developed areas (e.g., Beira and Maputo fuel corridors). − Limited investment in developing biofuel processing infrastructure.	− Poorly functioning agricultural services and limited availability of agricultural input for crop production. − Absence of agricultural extension to support smallholder farmers in producing Jatropha. − Confirmed technology (agronomy) and high yielding varieties for Jatropha are non-existent.	− Majority of Jatropha projects in areas with good communication and financial infrastructure. − Adapted technology to press oil from Jatropha seeds or to use Jatropha seeds or oil in lamps, stoves and generators exist, but are not widely available.
Institutions	+ Mozambique signed trade agreements exist that guarantee access of Mozambican Jatropha seeds and biodiesel to markets in SADC, Europe and the U.S. + Blending mandates to provide a domestic market for biofuel. + Policy framework for sustainable biofuels contributed to a more secure investment climate for biofuels.	+ Integration of criteria in policy framework for sustainable biofuels that stimulates contribution of biofuel projects to improved agricultural productivity. − Agro-ecological land zoning delayed, no guidance for investors. − Absence of policy to support the building of a Jatropha value chain. − Little trust among smallholder farmers in Jatropha.	− Absence of market to purchase Jatropha seed from smallholders. − No differentiation between land lease prices in urbanized and in remote areas. − Fiscal benefits and incentive structures did not stimulate investors to develop their projects in remote rural areas.
	− Lack of timely development, approval and implementation of biofuel policies and regulation.		

Table 3. *Cont.*

	Energy Niche-Regime Interactions	Agricultural Niche-Regime Interactions	Rural Development Niche-Regime Interactions
Interaction and collaboration	− No collaboration between agro-industrial projects to develop a joint agenda that could be defended in biofuel policy debates leading to legislation. − Limited exchange of experiences of Jatropha processing for local energy production among smallholder projects.	+ Sharing of agronomic data among agro-industrial projects and between researchers and projects. − Limited collaboration between agro-industrial projects in terms of their breeding research. − Limited exchange of experiences with Jatropha growing among smallholder projects.	+ Collaboration between civil society organizations in developing and defending a joint biofuel agenda. − Conflicts between agro-industrial projects and local communities on land rights and employment conditions. − Collaboration between well-intended NGOs and farmers in Jatropha projects led to high risks for farmers.
	+ Strong inter-ministerial collaboration in development of sustainability criteria for biofuels. − Limited multi-stakeholder collaboration. − Poor communication and low transparency on government legal procedures for agro-industrial Jatropha projects.		
Capacities and resources	− Lack of organizational capacity (and funding) to collect all produced Jatropha seeds for central processing.	− Lack of agronomic knowledge on Jatropha crop management with all stakeholders. − Policy did not provide funding to build capacity (e.g., through research and training) on Jatropha. + Recent adaptation of agro-industrial plantations' strategy to produce food while still investing in Jatropha research.	− Lack of skilled labor force. + Adaptation from mono-cropping to intercropping and hedges to decrease smallholders' risk. − Delayed exploration of by-products to increase economic feasibility of Jatropha.
	− Impact of the financial crisis decreased time for experimentation and learning.		

4.1. Infrastructure

A combination of biophysical, socio-economic and legal factors are known to guide investment location selection (e.g., [48,49]), and companies tend to cluster to benefit from sharing infrastructure. In line with these theoretical expectations, the existing fuel infrastructure in the corridors and in harbors provided an incentive for especially the agro-industrial Jatropha projects to locate themselves in these areas. Furthermore, many of these projects were aiming at supplying Jatropha oil to overseas markets, such as the EU, where incentive structures for trading biofuels were already in place. For these projects, being located near deep-sea harbors would reduce production costs and increase the overall profitability of production. An additional benefit was access to services, inputs and competent labor in these regions, for example, necessary for the maintenance of machineries and purchase of agro-chemicals, such as fertilizer and crop protection inputs. In more remote rural areas, agricultural extension infrastructure and the supply of agricultural inputs was limited, leading to a lack of support for Jatropha producing smallholders. Furthermore, the absence of communication infrastructure (e.g., access to the Internet) and financial infrastructure (e.g., banks) in remote rural areas made many Jatropha projects decide to establish themselves in developed regions. This created tension with achieving agricultural and rural development objectives, as the pressure on available agricultural land in these regions was already very high, and it would also contribute less to the rural development objectives pronounced by the Mozambican government.

The majority of smallholder and agro-industrial activities focused on the production of Jatropha seed, rather than on developing processing infrastructure. As a consequence, processing infrastructure remained largely absent. In terms of the knowledge infrastructure around Jatropha, we can conclude that government, researchers, companies and NGOs and civil society organizations did invest in developing the body of knowledge around Jatropha production. However, this research had different foci, was driven by different interests and consequently resulted in different outcomes. The alignment of research activities and the exchange of research findings was generally very limited.

4.2. Institutions

When we look at the formal institutions (*i.e.*, policies) promoting Jatropha, we conclude that the drivers for a national transition towards biofuels mainly focused on regimes of energy (diversification of the energy matrix, blending targets, domestic markets), agriculture (crop production on marginal lands, spill-over effects improving agricultural practices) and rural development (infrastructure, employment and income generation in remote rural areas). A big incentive for foreign investors to start production of biofuel in Mozambique was that the Mozambican government had signed treaties that gave them the right to freely export Jatropha seed, biodiesel and bioethanol to the European market. Apart from the government-led Jatropha seed distribution projects in 2004, several government policy development activities were initiated to challenge the existing (fossil) energy regime, such as the NBPS, the Biofuels Blending Regulation and the policy framework for sustainable biofuels. In developing policies, Mozambique was advanced compared to other African countries [26]. Nevertheless, these policies were not approved and implemented in a timely manner, and consequently, their contribution to creating a more secure investment climate for niche-level Jatropha projects in Mozambique was limited.

When specific fuel blending policies finally were approved, many of the Jatropha projects had already gone bankrupt.

Although new agricultural policy aims to support subsistence farmers to become entrepreneurs and focuses on value chains, this policy did not explicitly link up with Jatropha developments to challenge the existing agriculture or rural development regimes. There was little attention for developing a Jatropha value chain, and there were no markets in rural areas where farmers could sell their Jatropha seeds. In many other countries where Jatropha has been introduced, for example Mexico, China, India and Indonesia, the lack of value chain development was an important factor for its failure [50–53]. As the agro-industrial Jatropha biofuel projects were mainly located in developed regions, they did not contribute to unlocking the agriculture and development potential in remote rural areas, but rather increased pressure on land in regions where prime agricultural land was already scarce. Implemented regulation, such as the Code of Fiscal Benefits, which provides tax incentives for investors that locate themselves in remote rural areas, did not consider the benefits of locating projects in areas where infrastructure was already in place. A suggestion for further research could be to study scenarios where land can be purchased or leased at different prices depending on locations, also potentially strengthening the position of customary land users in negotiations with investors.

Furthermore, the more informal institutions, such as the customary land use, did not change significantly. However the experiences with Jatropha project implementation, dealing with land conflicts, disputed compensation and labor conditions have created awareness of the need to respect the process of free prior informed consent of rural communities in the case of land acquisitions (as also propagated by international bioenergy certification schemes) and strengthening the position of customary land users. Some of the individual smallholder projects reported on the impact of planting Jatropha hedges as a way to demarcate and claim farm land, but this was too case specific to initiate a regime change. What did change was the belief that Jatropha can contribute to sustainable agricultural and rural development. Through time, it became increasingly questionable whether the promotion of Jatropha among smallholder communities had actually contributed to rural development. Analysis of the carbon credit project demonstrated that only high resource-endowed farmers with surplus labor and land available would be willing to invest in a perennial crop such as Jatropha and that for less resource-endowed farmers, investing in Jatropha would provide a risk to the household's food security situation. Furthermore, the many cases of failure had resulted in reduced farmer trust in Jatropha and in the biofuel sector as a whole. Farmers distrust and abandonment did not only occur in Mozambique, but also in other countries, such as Indonesia and Mexico [50,53].

4.3. Interaction and Collaboration

The analysis of interactions and collaborations can be subdivided between interactions and collaborations (1) among different agro-industrial projects, smallholder Jatropha projects and within specific stakeholder groups, such as NGOs and civil society organizations and government; and (2) between agro-industrial, smallholder Jatropha projects and other stakeholder groups. Interactions and collaboration among the agro-industrial projects is two-fold. On the one hand, these projects were willing to exchange agronomic data, as was demonstrated during the UEM scientific seminar, where various projects presented the results of their agronomy experiments. Furthermore, several projects collaborated with Mozambican and foreign researchers and students on a broad variety of agro-ecological, social and economic research topics. On the other hand, agro-industrial projects were secretive about their Jatropha variety and breeding experiments, as high performing varieties could become one of the companies' major assets. Like in other countries (e.g., [54]), several projects experienced problems in collaboration with the surrounding farm communities due to land conflicts, disputes about compensation related to the land acquisition process and employment terms, compromising the potential contribution of these agro-industrial Jatropha projects to rural development [17]. Despite their common objective, producing sufficient Jatropha oil for the further development of the biodiesel market in Mozambique, agro-industrial Jatropha projects did not develop a representative body that could defend their interests in policy negotiations or that could build a joint research agenda from which the agro-industrial Jatropha sector as a whole could benefit. Civil society stakeholders did manage to organize and represent themselves and developed a joint agenda on how biofuel developments in Mozambique should contribute to sustainable rural development. Harmonization of smallholder Jatropha projects and the exchange of experiences between these projects was very limited and mainly occurred on an individual case-by-case basis. Collaboration between NGOs and farmers became quickly compromised when Jatropha turned out to be a risk rather than a catalyst of rural development, especially to less endowed farmers. Smallholder Jatropha projects did not need to hand in investment proposals for approval nor go through a land acquisition procedure, as the land remained in the hands of the customary user. Consequently, these projects were not formally evaluated by the government [44], and learning from these projects was relatively limited, despite the fact that the government continued to promote smallholder Jatropha production. Within the Mozambican government, there was active inter-ministerial collaboration, especially in the development of sustainability criteria for biofuels, addressing all three regimes [26].

When looking at interaction and collaboration across different groups of stakeholders, different conclusions can be drawn. In Mozambique, several policies were developed in isolation of private sector and civil society stakeholders. Although they were consulted during some stages of the policy development process, they did not actively participate in shaping the biofuel policy agenda. Communication about and transparency of government procedures, such as the approval of land titles and investment proposals, was poor, which contributed to an insecure investment climate for agro-industrial Jatropha projects. The Mozambican government did actively collaborate with researchers and donors and consulted private sector and civil society stakeholders in developing the national policy framework for sustainable biofuels [26]. In Tanzania, in contrast, not much policy was developed (e.g., no blending mandates, no temporary tax incentives), but a stronger collaboration between stakeholders did lead to a somewhat more conducive business environment for niche Jatropha experiments [8]. Nevertheless, also in Tanzania, the reality of low Jatropha yields caught up with the high expectations and initial enthusiasm about Jatropha.

4.4. Capabilities and Resources

With regard to the availability of capabilities and resources in the Jatropha sector in Mozambique, several conclusions can be drawn. Knowledge and expertise on and experience with Jatropha among policymakers, extension officers, NGO staff, researchers, entrepreneurs and farmers was largely absent. As a consequence, seed distribution, advice to smallholders and seed collection were not organized, and learning was mainly based on trial and error, requiring a high degree of flexibility and adaptive capacity for those involved. Some projects were more adaptive than others. The scale of operations influenced, to a large extent, the organizations' flexibility to, for example, relocate or adapt project activities if needed. For example, one of the smallholder projects relocated its activities from an area with the highest pest and disease pressure to an area with lower pressure [3]. The same project shifted away from Jatropha planting as monoculture in fields to planting in hedges, which was desired by farmers. The adaptive capacity and flexibility for individual smallholders involved in growing Jatropha is a different story. Experiences demonstrate that only a very small group of high resource endowed farmers had the ability to invest land, labor and other resources (e.g., fertilizer) in a crop of which they had little knowledge, for which yields were uncertain and for which no market was available [33]. Less resource endowed farmers could not run the risk of investing in Jatropha, which makes the country-wide promotion of Jatropha by the Mozambican government for political purposes highly questionable. For the majority of the agro-industrial Jatropha projects, relocating project activities was not among the options, as they had already heavily invested in plantation establishment. Their low adaptive capacity in many cases created a lock-in, where, despite agronomic problems and low economic viability, projects kept expanding in the hope of attracting additional investments. Many such Jatropha projects eventually went bankrupt. A handful of agro-industrial Jatropha projects that did manage to downscale Jatropha planting and increase variety and agronomy research efforts continued to operate, although on a much smaller scale. Several such projects have partly shifted to producing food crops as part of their survival strategy [44]. Although the literature showed that the use of Jatropha waste and byproducts, such as press cake, e.g., for making of briquettes, electricity provision or organic fertilizer, could be promising (e.g., [55,56]), these options were hardly explored. Furthermore, Jatropha could also provide other services, such as erosion control, providing a barrier to run-off water and topsoil particles dissolved in it, as is common practice in Ethiopia (e.g., [57]). Yet, research and interventions in both smallholder and agro-industrial projects remained entirely focused on Jatropha oil production.

In terms of the availability of financial and human resources, the financial crisis of 2008 has had a significant impact on the Jatropha sector and the biofuel sector as a whole in Mozambique [44]. Many companies have gone bankrupt, leaving behind large areas of cleared prime agricultural land and disillusioned employees. On the other hand, it has also resulted in a separation between opportunistic investors and companies and investors that do have a long-term commitment to Jatropha as a biofuel crop. Despite the political attention for and commitment to Jatropha in Mozambique, capacity building seemed not to be a priority, as the national agricultural research centers did not receive much Mozambican funding for research on Jatropha. Currently, with the discovery of gas and coal in Mozambique, the momentum for biofuels seems to have disappeared. This makes long-term investments in and commitments to the development and implementation of biofuel policy, research and development activities less likely. Regarding the availability and capabilities of human resources, some critical mass has developed in Mozambique. Several students who conducted studies on Jatropha plantations were later employed in these projects or started working for ministries or NGOs involved in the promotion or regulation of biofuels or bioenergy more broadly. Forced to deal with the overwhelming attention for Jatropha, the government of Mozambique has developed legislation and procedures, such as the land zoning and sustainability criteria, that can also be used or adapted for guiding other types of agro-industrial investments. It has also contributed to improved legislation for land acquisition and investment proposal approval, which has resulted in a more transparent investment climate for agro-industrial projects.

5. Conclusions

For several years, Jatropha has been promoted as the main crop for biodiesel production in Mozambique, promising a contribution to diversifying the national energy matrix, increasing agricultural productivity of marginal land and rural infrastructure and employment generation. Reality is different, as many agro-industrial Jatropha projects chose to focus on supplying foreign biofuel markets and located themselves on prime agricultural land in regions with good existing infrastructure, whereas the size of the area planted and the number of jobs created were approximately 2% of what was initially expected. For both agro-industrial and smallholder Jatropha projects, high yields were not achieved, due to a lack of productive varieties and agronomic knowledge. Many agro-industrial projects went bankrupt, and in smallholder projects, the majority of farmers were not able to produce, or lost their trust in producing, Jatropha.

The analysis of the structural conditions that can enable or constrain energy, agricultural and rural development niche-regime interactions have taught us a number of important lessons. First, to understand Jatropha developments in Mozambique, different niche-regime interactions and their mutual relations need to be understood. For example, the existing fossil fuel infrastructure was enabling in terms of fostering energy niche-regime interactions, but constraining in terms of fostering agricultural and rural development niche-regime interactions, as projects did not invest in improving the agricultural productivity of marginal land and developing infrastructure and employment creation in remote rural areas. This shows that structural conditions can be both enabling and constraining for transitions and that niche-regime interactions need to be understood in the context of specific country objectives. Second, to foster niche-regime interactions, an enabling environment consisting of conducive infrastructure, institutions, collaboration and interactions, capabilities and resources needs to be in place. With that, we do not imply that all biofuel infrastructure, policies, actor-networks and financial and human resources should be operational before promoting biofuel activities. What we do mean is that preconditions for improved stakeholder interaction, collaboration and learning can enhance adaptive capacity and flexibility to respond to challenges that form an inherent part of any change or transition process. Strategic niche management can create space for innovation, first to make the niche competitive under prevailing regimes and, second, to transform the incumbent regimes. With regard to promoting innovations among smallholders, the governments, NGOs and private sector should be very careful not to transfer the risks involved in transition processes to those who are already vulnerable. Thirdly, the existence of a multitude of niche experiments and an enabling environment is not a guarantee for success. The global financial crisis, the high fluctuation of fossil fuel prices and the discovery of other energy sources in Mozambique are just some of the many drivers that have influenced niche-regime interactions in Mozambique.

An important question is whether the Jatropha niche had a chance to develop at all. In the case of Jatropha in Mozambique, strategic niche management was limited as the niche-level projects were neither shielded against prevailing selection pressure, nor nurtured. Due to the negative agricultural performance of the crop and the global financial crisis, the narratives about Jatropha became increasingly negative, and investors in agro-industrial and smallholder projects imposed shorter time periods to earn returns on their investment, which reduced space for experimentation and learning. Whether commercially viable Jatropha varieties and good crop management practices will foster desirable energy, agricultural and rural development regime changes requires careful monitoring and reflection. For example, high yielding varieties cultivated as monoculture on mega-plantations may increase pressure on land that is already used by others, competition with food crop production or may function as a source for pest and diseases problems. This shows how successes or failures in transition processes depend very much on the timeframe within which they are analyzed. A decade of boom and bust of Jatropha in Mozambique did initiate the development and implementation of policy, regulation and incentive structures and enhanced (adaptive) capacity. It also created an experience of collaboration between ministries, leading to more policy coherence and a more transparent investment climate. These structural conditions could form the basis for an enabling environment for capturing future biofuel momentum in Mozambique.

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Author Contributions

Between 2008 and 2012 Maja Slingerland led a multidiscliplinary programme on the impact of bio-energy investments on small scale farmers and rural development in Mozambique. This programme involved extensive engagement with CEPAGRI, different Mozambican ministries, Jatropha companies and Jatropha promoting NGOs as well as with Eduardo Mondlane University and the Dutch Embassy. During that time she was involved in direct data collection and in supervision of MSc studies with the different partners, policy advice and the publication of different papers on biofuels in Mozambique.

Between November 2008 and July 2012, Marc Schut worked as action researcher in Mozambique. He conducted and published various studies on biofuels in Mozambique, facilitated a multistakeholder platform in developing a policy framework for sustainable biofuels, and supervised MSc-students. Marc Schut and Maja Slingerland jointly conceived and designed the study based on prior separate and collective data collection, complemented with literature research. They jointly made the analytical framework of the paper, and used it to analyze the data, discuss the outcomes and draw conclusions.

Conflicts of Interest

The authors declare no conflict of interest.

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