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Article

Biofuels for a Greener Economy? Insights from Jatropha Production in Northeastern Ethiopia

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Abstract: Many observers view Jatropha as a miracle plant that grows in harsh environments, halts land degradation and provides seeds for fuel production. This makes it particularly attractive for use in Ethiopia, where poverty levels are high and the degradation of agricultural land is widespread. In this article, we investigate the potentials and limitations of a government-initiated Jatropha project for smallholders in northeastern Ethiopia from a green economy perspective. Data are based on a 2009 household survey and interviews with key informants, as well as on a 2012 follow-up round of interviews with key informants. We conclude that the project has not contributed to a greener economy so far, but has the potential to do so in the future. To maximize Jatropha's potential, interventions must focus mainly on smallholders and pay more attention to the entire biofuel value chain.

Keywords: green economy; biofuels; Jatropha; Ethiopia; smallholders

1. Introduction

Many observers view Jatropha as a miracle plant that grows in harsh environments, halts land degradation and provides seeds for biofuel production. This makes it particularly attractive for use in Ethiopia, where poverty levels are high and the degradation of agricultural land is widespread. Research on private biofuel investments in Ethiopia and elsewhere has shown that Jatropha production does not reduce greenhouse gas emissions [1] and is not economically viable on its own [2]. However, Jatropha production can be beneficial if the plant is cultivated as hedges within a multifunctional agricultural system [3].

In the study described below, we examined a government-sponsored Jatropha project in northeastern Ethiopia that was implemented as part of Ethiopia's green economy and biofuel strategy. Our study sought to answer one key overarching question and two more specific questions: (1) Is the project contributing to a greener economy? (2) Do local smallholders benefit economically from the project by selling Jatropha products? (3) Can energy products from Jatropha replace smallholder households' current sources of energy?

1.1. Green Economy

At Rio+20, the 2012 United Nations Conference on Sustainable Development, the creation of a "green economy" was declared to be an important means of achieving sustainable development and eradicating poverty [4]. The concept of a green economy emphasizes the potential for positive interaction between the environment and continuing economic growth. It has gained popularity in response to the food and financial crises of 2008 [5]. Central to the concept of a green economy is the idea that greater economic value must be attached to nature and ecosystem services and that this will give rise to new markets supported by policy incentives that promote sustainable investment and sustainable consumption. This, in turn, is expected to trigger ground-breaking technological innovations emphasizing greater efficiency [4].

Generally, proponents of the green economy concept argue that economic growth and environmental sustainability are not mutually exclusive. They believe that win-win scenarios are possible and point to examples, such as renewable energy systems or carbon-trading mechanisms (e.g., REDD+) [6]. By contrast, many opponents of the green-economy concept believe it maintains the *status quo*, reinforcing capitalistic structures rather than encouraging much-needed systemic change. They argue that increased valuation of natural resources and ecosystem services will lead to further market expansion into the commons, under the pretext of environmental protection, resulting in more and greater inequities that harm local communities [7,8].

Indeed, how best to achieve greener economies is a subject of heated debate, and people's notions of what constitutes a green economy differ depending on the context [9–11]. Industrialized and emerging market countries' continued economic growth appears highly dependent on the development of innovative, low-carbon technologies and the implementation of related comprehensive policies. The economic growth of developing countries, by contrast, continues to rely on expanding use of natural resources and increased agricultural production. For industrialized countries, the pursuit of a green economy provides an opportunity not only to mitigate climate change, but also to overcome recent economic crises by ramping up investment in innovative ("green") technologies. Emerging market countries, on the other hand, face multiple challenges due to increased economic growth and changing consumption patterns, such as increased meat consumption and the use of greenhouse-gas emitting technologies. For these countries, reducing greenhouse gas emissions while creating jobs appears especially challenging, and environmental problems and social inequalities continue to prevail in these contexts. Developing countries face many of the same problems and must additionally tackle the challenges of widespread poverty [10].

Thus, at the Rio+20 conference, governments stressed the importance of customizing the green economy concept to fit individual national priorities [12]. In Ethiopia, where a majority of the population depends on small-scale agriculture, the implementation of a green economy must account for the needs of smallholders [10]. If not, relying on the environment to curb a green economy bears the danger of disproportionately affecting the most vulnerable groups, as most of them rely directly on natural resources for their livelihoods.

1.2. Biofuels

With the rise of the green economy concept, the case for biofuels acquired new momentum [13]. Initial promoters of biofuel investments pointed to many possible benefits. Eventually, however, controversies arose regarding biofuels' performance in terms of greenhouse gas emissions, their possible negative effects on the environment, their ambiguous impact on rural development and, above all, the related use of cropland to produce fuel instead of food [14–18]. Civil society organizations, in particular, were very active in stirring up public debate about biofuel investments [19,20]. One of the most radical stances on biofuels called for a moratorium on these investments until such time as appropriate policies, structures and mechanisms could be put in place to enable poorer populations to benefit directly from biofuel production, storage, processing and transport [21,22]. Other groups, even some acknowledging biofuels' potential benefits, recommended ending support for biofuels that threaten food supplies or have negative impacts on the environment [23–25].

At the same time, reducing dependence on fossil fuels remains a crucial requirement for sustainable development, and biofuels are still seen as a possible alternative to fossil fuels, especially in the transport sector. In 2011, biofuels accounted for approximately 3% of the fuels used for transport; still, a very small share [26]. Nevertheless, biofuels' share of the energy mix is expected to grow over time as policymakers worldwide encourage greater biofuel production with tax exemptions, as well as blending and consumption mandates and subsidies [19,23,27].

1.3. Green Economy and Biofuels in Ethiopia

Ethiopia's vision for greening its economy, or Climate-Resilient Green Economy (CRGE) strategy, is based on its national Growth and Transformation Plan (GTP), which seeks to enable the country to reach middle-income status by 2025 [28,29]. Launched in 2011, the CRGE aims to support improvement of agriculture, sustainable management of natural resources and poverty reduction. The strategy is expected to play a major role in Ethiopia's near-term growth, transforming the country into a "green economy front runner" while fostering development and sustainability [28]. The ambitious CRGE strategy rests on four pillars: (1) improving agricultural practices to increase food security; (2) protecting and re-establishing forests for direct economic benefit and for ecosystem services, including enhanced carbon stocks; (3) expanding electricity generation from renewable sources; and (4) leapfrogging inefficient technologies and instead implementing modern, energy-efficient technologies in transport, industry and infrastructure [28]. Investment in agriculture is considered central to the success of the plan, as it is avoiding "conventional development paths" that lead away from low-carbon solutions [28].

Included in the fourth pillar of the CRGE strategy are efforts toward decarbonizing transport fuel, as well as producing biodiesel and ethanol. The planned implementation of 5% biodiesel and 15% ethanol blends by 2030 would mean replacing 0.28 billion L of diesel and 0.09 billion L of gasoline. The abatement potential of biodiesel is projected to be 0.7 megatons (Mt) of CO_2; for ethanol, the projected figure is 0.2 Mt CO_2. [28]. The Ethiopian government aims to increase its annual production of biodiesel to 1.6 million L by 2015, anticipating that this will generate USD one billion in revenues [29]. The preferred feedstocks for producing biodiesel in Ethiopia are Jatropha, castor and palm oil, while ethanol is primarily produced from sugarcane [30]. While government-owned sugar factories have over 30 years of experience in producing ethanol from molasses [31], blending and distribution activities for transport only began in 2009 [32,33]. Efforts to produce biodiesel, by contrast, only began to emerge in 2005 with the support of private investors and were given further support with the release of the Ethiopian government's "Biofuel Development and Utilisation Strategy" in 2007 [30,34].

The government's stated blending goals will require approximately 25,000 ha of arable land to produce sugarcane for ethanol, as well as 486,000 ha of arable land to produce biodiesel [28]. Most recently, the Ethiopian Ministry of Water and Energy declared that a total of one million ha of land were suitable for Jatropha cultivation [35]. However, their definition of available and suitable land is vague. Currently, the Ministry of Water and Energy is conducting a baseline, suitability and value chain study on the biofuels development of Ethiopia in order to map the available and suitable land more precisely [36]. Further, the exact extent of biofuel feedstock plantations in Ethiopia is unknown, and estimates of current land area under Jatropha cultivation vary greatly [35,37]. Thus, data on available and suitable land, as well as current investments should be read with a certain degree of skepticism [38,39].

1.4. Jatropha

Jatropha has been promoted globally as a plant that may be used to make biodiesel and carries the added advantage of helping to rehabilitate degraded lands [40,41]. Using simple technology, high quality oil may be extracted from Jatropha seeds and used as biodiesel [42]. It can serve as a substitute for conventional fuels, such as kerosene, diesel or fuelwood. Jatropha is seen as contributing to the restoration of degraded land in at least two ways: first, according to its planting method, for example, when cultivated as dense hedges that form contour lines across slopes, in gullies and using half-moon techniques [43–45]; second, Jatropha's root structure—featuring one vertical root and four lateral roots—is believed to naturally stabilize slopes and help control soil erosion [45,46].

In the Bati region of Ethiopia, the dual use of Jatropha to provide energy and to rehabilitate land has been practiced to some extent for at least 40 years. Today, however, cultivation of Jatropha plants is being promoted at a never-before-seen scale. Traditionally, farmers in Ethiopia mainly used Jatropha plants as living fences and as a structural means of conserving soil and water [47,48]. Now, in connection with green economy goals, the Ethiopian government has begun promoting cultivation of Jatropha to make biodiesel for transportation [28,30]. At the same time, several private Jatropha production projects, launched as early as 2005, have been cancelled, in part due to concerns about economic viability [2].

2. Study Site and Methods

The in-depth case study described here was one of three conducted at different sites in Ethiopia within the Bioenergy in Africa Project (BIA) [49]. Between 2009 and 2011, the BIA carried out biophysical and socioeconomic studies on the potentials and risks of Jatropha cultivation in nine case study areas in Tanzania, Kenya and Ethiopia. The area where our study took place, Bati woreda ("district"), is located in northeastern Ethiopia's Oromiya administrative zone of the Amhara region, along the eastern border of the highlands facing the Danakil lowlands.

Our methods comprised the following: a literature review, interviews with key informants in September, 2009, as well as a household survey, focus group discussions and additional interviews with key informants in October, 2012. Interviews with key informants were held at the district and local level with members of the government, NGOs, community leaders and farmers. Our literature review provided us with an overview of the status of green economy efforts and biofuels in Ethiopia. Initial interviews with key informants supported the development of the household survey and served to complement and contextualize our other data. The focus group discussions were important to understand the dynamics of argumentation and justification for different positions, as well as collective patterns of orientation [50].

The household survey was conducted within five peasant associations—Kurkura, Ournguo, Mumed, Mutuma and Jeldity—and included Jatropha growers and non-growers (n = 150). The questions covered people's general resource endowments, farming activities, Jatropha use and cultivation practices and energy situation. Most interviewees (men and women) were the head of their household, whenever possible. This survey was applied in all case study sites of the BIA. In each study site, questions specific to the local situation were added. Gender dimensions were not captured through gender-disaggregated interviews, but rather through individual questions. In the following, references to the views or activities of smallholders or households are taken from the statements of individuals who spoke on behalf of their entire household. Data from the household survey were analyzed using SPSS predictive analytics software. Interviews and focus group data were analyzed, forming inductive categories following the principles of qualitative content analysis [51].

3. Results

3.1. Traditional Use, Current Extent and Intended Processing of Jatropha in the Bati Area

Jatropha has been grown for about four decades, primarily as a fencing plant, in arid regions of Bati woreda [47,48]. Its local Amharic name is "*Gullo*", but farmers also refer to it as "*Ayderkie*", "*Yedinber Shimagilie*" and "*Yedinber Astaraki*", meaning "drought resistant", "border mediator" and "good farmland demarcation", respectively, and indicating farmers' primary uses for the plant [30,47]. In addition to its use as a living fence, Jatropha is also used as fuel for lamps, as fertilizer and for medicinal purposes in parts of northeastern Ethiopia [47]. Individual smallholders in Bati have an average of 990 Jatropha trees or 300 m of Jatropha hedges on their property. After establishing its use as a living fence, farmers also began cultivating Jatropha for the purpose of soil and water conservation, first growing it in contour lines across slopes and later using it for the rehabilitation of gullies. Traditionally, men cultivate Jatropha and take care of conservation measures, while women and children gather the seeds. Most recently, with the emergence of a market for Jatropha, women began selling the seeds.

In only three years, the area under Jatropha increased more than two and a half times, covering almost 2% of Bati district's total land area (124,696 ha) by early 2012. In 2009, the total district area under Jatropha cultivation was 892 ha [52]; in early 2012, it was 2,405 ha, of which 1,024 ha were planted for the purpose of afforestation in the 2011/12 season. The remaining 1,381 ha were cultivated prior to 2011/2012, according to the following breakdown: 517 ha on communal land; 322 ha for gully rehabilitation; 427 ha on farmlands; and 114 ha as a living fence [53]. In the district's communal areas, Jatropha plants are propagated using cuttings and seedlings by the local agricultural office, as well as by the NGO known as the Organization for Rehabilitation and Development in Amhara (ORDA). In 2009, some farmers sold their Jatropha seeds on the market, either to ORDA or to intermediary traders who would sell them to biofuel companies operating in other parts of the country.

To process Jatropha seeds and maximize value, the ORDA and the Ethiopian Environmental Protection Agency invested 1.5 million Ethiopian birr (about USD 85,000) in the construction of a biodiesel plant. The factory, which was not yet running as of 2012, has the potential to extract up to 300 L of Jatropha oil per day [41]. Initially, the plan was to train local people to operate the machinery and run the plant. Accordingly, 400 farmers from four peasant associations were organized to form a cooperative. Eventually, however, the investors decided it would be necessary to hire external experts in addition to help run the factory.

3.2. Traditional Jatropha Yield, Workload and Income in the Bati Area

In Bati, farmers traditionally prune Jatropha hedges once a year in order to minimize competition for sun, water and nutrients, as well as to maximize their performance as a soil and water conservation measure. However, this appears to negatively impact yields. Farmers reported an average yield of 0.5 kg of Jatropha seeds per meter of hedge [48]. This is at the lower end of BIA yield estimates [3], which suggest an average yield of 1 kg/m (mean) for hedges, with a minimum of 0.5 kg/m and a maximum of 2 kg/m, depending on the agro-ecological setting, production system and main intended use of the Jatropha plant. These BIA yield estimates rely on averages obtained over the lifespan of the plant and are based on a spacing of 0.3 m between stems, *i.e.*, 3.3 trees per meter. In Bati, 300 m were planted with 990 Jatropha trees, which results in 2.8 trees per meter. Data on Jatropha seed yields from communal land in Bati were unavailable, since Jatropha plants reach maturity 3–4 years after planting [54]. At the time the data were collected for the present study in 2009, the Jatropha plants on communal land were not yet bearing seeds.

Farmers described their Jatropha-related workload as minimal, since seeds were collected in between other activities. Indeed, at the time of the household survey and interviews with key informants in 2009, farmers were not systematically harvesting and dehulling Jatropha seeds, because they considered the market to be unstable or virtually non-existent. These time-consuming activities might increase as the number of Jatropha plants increases. The workload for picking can vary considerably depending on yield rates and plantation type. Hedges generally produce lower yields than plantations. Hedges mainly consist of either wild stands or plants grown for the purpose of soil and water conservation, while plantations are generally well-managed cultures [55]. To estimate the potential workload of cultivating

Jatropha for seed oil, we relied on a study conducted in a similar setting in Tanzania [56]. In that study, researchers calculated that for 5 kg of Jatropha seeds, 4.1 h are used to collect the seeds and 3.4 h are needed for dehulling.

Opportunity costs of labor can present a challenge if seeds are collected systematically. For our analysis, we thus assumed that it would be necessary to hire additional agricultural workers to complement family labor when harvesting Jatropha seeds. To calculate the costs of this additional labor, we used local market labor rates (USD 2 per day) instead of shadow wages. The estimates of average labor costs for agricultural workers and of market prices for Jatropha seeds resulted from our own research. In 2009, the household-level labor cost of producing a kilogram of Jatropha seed was greater than the market price that could be obtained for that same kilogram of Jatropha seed (see Table 1). Estimates of the market prices in 2009 and 2012 were derived from interviews with key informants. Estimates of labor costs in 2012 are based on our survey data from 2009, with the figures adjusted for inflation.

In 2009, individual farmers collected an average of 27.5 kg dehusked seeds and sold them at a price of 2 birr (approximately USD 0.17) per kilogram. Production costs were almost nil, because farmers did not buy any Jatropha seeds or stems to propagate, nor did they use any fertilizer or pesticides. Smallholders thus earned an average of USD 4.86 for the 27.5 kg Jatropha seeds by selling them at the local market in 2009. This is very little when compared with the income they earned from their main staple crop, sorghum. In the same year, individual farmers had an average yield of 550 kg of sorghum, potentially earning them an average of USD 250 for the year. This is 50-times the amount they earned from Jatropha seed. Nevertheless, Jatropha could provide additional income if farmers would collect all of the seeds from their 300 m hedges. According to average yield values in Bati—0.5 kg of Jatropha seed per meter of hedge—individual farmers could harvest an average of 150 kg seed from their Jatropha trees annually. Based on this estimate, individual farmers who collected all of their seeds could have earned $150 \times 0.17 - 30 =$ USD − 4.5 (Jatropha seeds in kg × market price in USD − labor costs in USD = potential income in USD) in the year 2009; and earned $150 \times 0.56 - 43.50 =$ USD 40.50 in the year 2012.

3.3. Household Energy Sources and Household Budget in the Bati Area

Farmers' main sources of energy in the study area were firewood, diesel and batteries (see Table 2). Kerosene, a popular fuel throughout eastern Africa [57], was seldom used in Bati. This is because kerosene costs twice as much as diesel (USD 0.40 per liter *vs.* USD 0.20 per liter). At the time of our household survey, in 2009, Jatropha oil and biodiesel were not used at all by farmers in the study area because no local oil extraction or biodiesel facilities existed. Firewood was mainly used for cooking; approximately one fifth of respondents also used firewood for lighting and heating. Diesel was mainly used in lamps, and batteries were primarily used in flashlights. The average weekly cost of these three main energy sources combined (median values) was USD 7.10. At USD 6.40 per week, firewood accounted for the lion's share. The average weekly cost of diesel and batteries combined was less than one dollar. These figures reflect the costs that resulted from the survey. They do not factor in that most households gather firewood for themselves and even sell firewood on the local market.

Table 1. Overview of the workload for Jatropha seed collection and dehulling [56], corresponding labor costs in Bati, local market prices in 2009 and 2012 and calculated income from Jatropha seed.

			2009			2012		
Jatropha seeds (kg)	Collection (hours)	Dehulling (hours)	Labor costs (USD)	Market price (USD)	Income (USD)	Labor costs (USD) (Inflation-adjusted: inflation rate 2010 (consumer prices, annual %): 8.14; 2011: 33 (estimates); 2012: 21.7 (estimates) ([58])	Market price (USD) (Average sell rate for March to May, 2012: 0.056 ETB to USD)	Potential income (USD)
1	0.82	0.68	0.2	0.17	−0.03	0.29	0.56	0.27

Table 2. Average household usage and costs of the three main energy sources—firewood, batteries and diesel—in the study area in 2009.

Firewood					
Loads per week		**Costs per load in USD**		**Costs per week in USD**	
Mean	Median	Mean	Median	Mean	Median
4.8	4.0	1.4	1.4	6.6	6.4
Batteries					
Number per week		**Costs per battery in USD**		**Costs per week in USD**	
Mean	Median	Mean	Median	Mean	Median
8.6	7.0	0.05	0.05	0.43	0.1
Diesel					
Liters per week		**Costs per liter in USD**		**Costs per week in USD**	
Mean	Median	Mean	Median	Mean	Median
2.2	0.5	0.2	1.1	0.5	0.6

To assess the financial burden of household energy costs, we compared these expenditures with households' purchasing power. With a gross national income (GNI) per capita of USD 340 (Atlas method) in 2009 [59], Ethiopia's average income per person was less than USD 1 per day in 2009. Even if adjusted for purchasing power parity, Ethiopia's 2009 GNI per capita could still be considered very low at USD 910 or less than USD 3 per day per person [59]. Thus, household energy expenditures were and are a significant financial burden for farmers in the study area; a burden that could be alleviated with alternative energy sources and/or additional sources of income. In 2009, the average annual energy expenditure of households in the study area was USD 370, making up approximately 18.5% of individual households' annual budget (370 USD/(2.2 × 910 USD) = 0.185 (18.5%). That is: annual energy expenditure/(average number of household members over the age of 15 × annual income) = share of annual energy expenditure in percentage. Note: this assumes that only household members over the age of 15 contribute significantly to household income.).

4. Discussion and Conclusions

Our study shows that at least two main purposes for Jatropha cultivation—one old, one relatively new—overlap in Bati. First, local farmers in Bati have traditionally grown Jatropha hedges as living fences and as a means of soil and water conservation. Their Jatropha plants serve to protect water points and retain soil and water on fields, enhancing food production. Second, the Ethiopian government has begun promoting Jatropha cultivation as a means of halting land degradation on so-called marginal lands and producing biofuel for transport. The former, traditional practice of Jatropha cultivation is embedded in a multifunctional farming system; the latter, government-sponsored Jatropha cultivation seeks to scale up traditional Jatropha cultivation, leading to "Jatropha tree landscapes" for fuel production.

This article provides important insights into Jatropha's potential role in a greener economy, but it also has some limitations. In 2009, Jatropha interventions in Bati still focused on hedges. The questions of the survey were thus developed to gain an overview of Jatropha cultivation practices and were not designed to analyze the overall performance of the Jatropha project, including the commons. Nevertheless, as this project is quite unique (especially considering the area's longstanding experience with Jatropha and more recently), we believe that the existing information enables improved understanding of the Bati area's nascent biofuel economy.

Does this Jatropha project contribute to a greener economy? So far, growing and processing of the Jatropha plant has not contributed to a greener economy in the study area, e.g., by replacing fossil fuel or by alleviating poverty. In order to begin economically benefitting from Jatropha as a biofuel, more emphasis is needed on farmers' workload, on local processing of Jatropha seeds, on the creation of a stable market and on training and establishing teams of professional biodiesel workers. To date, ORDA and the Ethiopian government have mainly focused on encouraging more and greater cultivation of Jatropha. Relatively little attention has been paid to the other parts of the value chain, resulting in an incomplete biofuel supply chain. The recently constructed biodiesel factory in Kombolcha, nearby the study area, nevertheless provides an opportunity for local development. If large quantities of Jatropha seed can be systematically harvested, processed and sold, this will likely facilitate a stable market and a better price for farmers.

Regarding Jatropha's ecological performance, it is very likely that increased use of Jatropha will lower soil erosion and retain water, since the plant has been traditionally used for decades in the Bati area for hedgerows and as a means of stabilizing gullies [60], with positive outcomes. Indeed, Jatropha cultivation likely mitigates land degradation and creates carbon sinks [61]. Nevertheless, it is only just becoming possible to assess the specific ecological impacts of Jatropha plantations on communal lands and of increased cultivation of Jatropha hedges. These impacts require further research.

Do local smallholders benefit economically from the project by selling Jatropha by-products? Thus far, over the short term, smallholders in Bati have not benefitted economically from the project, and it remains unattractive for smallholders to collect the seeds systematically. Over the long term, however, there might be potential for smallholders to benefit economically. For example, additional Jatropha seeds harvested from communal areas could increase smallholders' incomes. Relief from energy costs is another possibility: comprising 18.5% of the average farmer's total household budget, energy expenditures are a significant financial burden that could be alleviated with alternative energy sources—e.g., Jatropha oil or biodiesel for home use—or additional income activities. However, as biodiesel from Jatropha is currently intended for transport and not for domestic use, farmers would need to buy biodiesel from the factory or process the seeds themselves. This, in turn, might strain households' budgets. Alternatively, if farmers were to avoid buying biodiesel and focused on selling their Jatropha seeds as an additional income activity, they could benefit economically if Jatropha seed prices continue to rise. Between 2009 and 2012, the market price for Jatropha seed increased more than three-fold in Bati. The price may increase even more once the local biodiesel plant is up and running properly. Finally, additional revenue could be generated through the sale at local markets of Jatropha products, including Jatropha cuttings for hedge making, seeds for oil extraction and latex for medicinal purposes, among other possibilities.

Can energy products from Jatropha replace smallholders' current household energy sources? At the moment, the low price and ease of use of batteries in flashlights makes it appear very unlikely that Jatropha products will replace them. However, increasing the availability of diesel and Jatropha oil to power lamps might incentivize farmers to consider using lamps rather than flashlights as a lighting source. To substitute 1 L of diesel, about 1.1 L of Jatropha oil are needed [60]. To produce 1 L of Jatropha oil, 5 kg of seeds or 10 m of Jatropha hedges are needed. To replace the annual diesel consumption of one household in Bati—that is, about 114 L—approximately 570 kg of seeds or 1140 m of Jatropha hedges would be needed. At present, however, individual smallholders only own 300 m of Jatropha hedges on average. Thus, they would need to triple the amount of Jatropha hedges they own in order to replace their current diesel consumption with Jatropha oil. One possible household-level scenario could be as follows: on one hectare of land, at least 10 hedgerows could be planted horizontally at 10 m intervals without compromising crop production. This would result in the 1000 m of Jatropha hedges required by one Bati household to replace its annual diesel consumption. However, to reliably determine whether Jatropha-based energy products are capable of replacing conventionally used energy sources over the long term, more data are needed on energy use and provision, future market scenarios and stakeholders' perceptions.

Overall, Jatropha does not contribute to a greener economy in Bati, but bears the potential. For this to happen, smallholders must be put at the center of Bati's Jatropha project, and more attention must be paid to the whole biofuel value chain and to the whole agricultural landscape. Smallholders are the main producers and caretakers of Jatropha plants in Bati, and with proper training, they could also be a source of labor on behalf of Jatropha biofuel value chains. Jatropha's cultivation and use for decades in the region can be seen as an advantage—smallholders know and accept the plant. However, systematic maintenance of Jatropha plants, collection of seeds and distribution of benefits require a high level of organization and communication. Thus, access and use of Jatropha on communal land should be regulated and discussed with different users. Many of the Jatropha project's trees were planted on communal land that was still used for browsing animals in 2009 and 2012. Once the plants are fully grown, they may block such animals from accessing plantations and prevent them from consuming enough fodder. This could lead to increased pressure on natural resources elsewhere and negatively impact ecosystem services. Finally, the scope of efforts to establish a biofuel economy in the region should be expanded to include assessment of Jatropha by-products that may be equally beneficial economically.

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Author Contributions

Brigitte Portner contributed to conception, design, analysis, writing and interpretation of the research article. Albrecht Ehrensperger contributed to case study conception and design as well as to data analysis and interpretation. Zufan Nezir contributed to data collection. Thomas Breu contributed to the conceptual design of the article. Hans Hurni contributed to the interpretation and verified the analysis. All co-authors contributed to the writing of the final research article.

Conflicts of Interest

The authors declare no conflict of interest.

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