Energy Policy 39 (2011) 5116–5128

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Space for innovation for sustainable community-based biofuel production and use: Lessons learned for policy from Nhambita community, Mozambique

Marc Schut [a,*], Annemarie van Paassen [a], Cees Leeuwis [a], Sandra Bos [b], Wilson Leonardo [c], Anna Lerner [d,1]

[a] Communication and Innovation Studies, Wageningen University and Research Centre, P.O. Box 8130, 6700 EW Wageningen, The Netherlands
[b] Social Engineer and SME-specialist, FACT Foundation, Eindhoven, The Netherlands
[c] Plant Production Systems, Wageningen University and Research Centre, Wageningen, The Netherlands
[d] Climate Change Mitigation Team, Global Environment Facility, World Bank, Washington, DC, USA

ARTICLE INFO

Article history:
Received 7 January 2011
Accepted 30 May 2011
Available online 25 June 2011

Keywords:
Biofuels
Jatropha
Mozambique

ABSTRACT

This paper provides insights and recommendations for policy on the opportunities and constrains that influence the space for innovation for sustainable community-based biofuel production and use. Promoted by the Mozambican government, Nhambita community established jatropha trials in 2005. Initial results were promising, but crop failure and the absence of organized markets led to scepticism amongst farmers.

We start from the idea that the promotion of community-based biofuel production and use requires taking interactions between social–cultural, biophysical, economic, political and legal subsystems across different scales and levels of analysis through time into account. Our analysis demonstrates that heterogeneous farming strategies and their synergies at community level should be carefully assessed. Furthermore, national and international political and legal developments, such as the development of biofuel sustainability criteria, influence the local space in which community-based biofuel developments take place.

We conclude that *ex-ante* integrated assessment and creating an enabling environment can enhance space for sustainable community-based biofuel production and use. It may provide insights into the opportunities and constraints for different types of smallholders, and promote the development of adequate policy mechanisms to prevent biofuels from becoming a threat rather than an opportunity for smallholders.

1. Introduction

Biofuels are high on the global political agenda, and many governments are exploring the production, processing and use of biofuels as part of a transition towards a more bio-based economy. Objectives for promoting biofuels vary across political levels and geographical locations. In many developing countries, governments perceive the production and use of biofuels as a pathway out of poverty because it may reduce the dependency on fossil fuel imports, create employment and increase revenues from export. As in many other Sub-Saharan African (SSA) countries, the Mozambican government is exploring: "[T]he potential for decentralized and renewable energy options for meeting energy needs" (Jumbe et al., 2009, p. 4982). Mozambique is seen as a promising country for biofuel production (Batidzirai et al., 2006). The recently approved National Biofuel Policy and Strategy (NBPS—Resolution 22/2009) underlines the Mozambican government's commitment to biofuels to improve energy security and to stimulate socioeconomic development, particularly in the rural areas (Government of Mozambique, 2009). The NBPS provides guidelines for the long-term development of the commercial biofuel sector in Mozambique but is also concerned with sustainable smallholder and community-based biofuel production and use. As the pace of rural electrification in Mozambique has been much slower than expected (Arthur et al., 2010, p. 7247), community-based biofuel production and use provides an interesting option to meet energy demands in rural areas that could consequently function as a catalyst for stimulating rural socioeconomic development (Jumbe et al., 2009, p. 4982).

Although the emerging commercial biofuel sector has been analysed and compared with the Mozambican government's policy objectives (cf. Schut et al., 2010c), systemic analyses of existing smallholder or community-based biofuel projects in

* Corresponding author. Tel.: +31 317 484635; fax: +31 317 486094.
E-mail addresses: marc.schut@wur.nl (M. Schut), annemarie.vanpaassen@wur.nl (A. van Paassen), cees.leeuwis@wur.nl (C. Leeuwis), sandra-bos@live.nl (S. Bos), wilson.leonardo@wur.nl (W. Leonardo), klerner@worldbank.org (A. Lerner).
[1] Former GTZ Regional Technical Advisor to SADC Energy Sector, Maputo, Mozambique.

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.05.053

Mozambique are scarce, but equally crucial for operationalizing and implementing the government's NBPS. Because smallholders in Mozambique and in other African countries are considered to play an important role in the growing of energy crops (Jumbe et al., 2009, p. 4984), understanding the complexity of smallholder farming is essential, as it makes bioenergy policies fundamentally different from other (rural) energy policies. The objective of this paper is to provide insights into the opportunities and constrains that influence the innovation space for sustainable community-based production and processing of biofuel feedstock for localized use or for local marketing (henceforth referred to as 'community-based biofuel production and use') (cf. Mangoyana and Smith, 2011, p. 1287). In so doing, we hope to sensitize strategic thinking when designing and implementing biofuel policies, and respond to the need for more effective and proactive policy mechanisms to support responsible and sustainable community-based biofuel production and use; in Mozambique, but also in other SSA countries (cf. Verdonk et al., 2007; van Eijck and Romijn, 2008).

The paper draws on lessons learned from Nhambita community in Mozambique, one of the first communities that complied with the government's request to produce *Jatropha curcas* Linnaeus (henceforth abbreviated as jatropha), a small tree or shrub that produces toxic grain with a relatively high oil content (between 30% and 35%) (Jongschaap et al., 2007; van Eijck and Romijn, 2008; de Jongh, 2010). The initial government proposal (which dates from 2004) stated that 5 ha of jatropha were to be planted in each of Mozambique's 128 districts, using underutilized or empty marginal soils to avoid competition with food production (Schut et al., 2010c, p. 5152). Although the majority of the projects were unsuccessful,[2] the Mozambican government continues to perceive jatropha as a high potential biofuel crop for community-based biofuel production. Furthermore, jatropha was selected as one of the four officially approved biofuel feedstock in the NBPS[3] (Government of Mozambique, 2009, p. 14). It is important to mention that, as part of operationalizing and implementing its NBPS, the Mozambican government actively supported this research to generate insights on the opportunities and constrains for responsible and sustainable community-based biofuel production and use.

Section 2 provides the research approach and methodology, followed by background information on Nhambita community in Section 3. Section 4 describes and analyses the introduction of jatropha and pigeonpea in Nhambita, followed by Section 5 that presents three case-study farms to explore farming strategies in the community. Section 6 assesses the potential for local processing and marketing of jatropha oil, after which the political and legal developments are described in Section 7. Subsequently, the findings are analysed and discussed in Section 8, followed by Section 9 that provides the main conclusions and recommendations for policy.

2. Research approach and methodology

We start from the idea that understanding the introduction and performance of an agricultural innovation like jatropha as part of a community-based biofuel strategy requires integrated assessment or an innovation systems approach. Firstly, this approach acknowledges that agricultural innovation is not just about new technologies, but that space for innovation is embedded in and constituted by dynamics between social–cultural, biophysical, economic, political and legal subsystems (Fig. 1) (Klerkx et al., 2010; Schut et al., 2010b; Leeuwis and Aarts, 2011). Supporting innovation processes or analysing space for innovation therefore requires cutting across the individual subsystems and providing integrated and holistic analysis of systems (cf. Smits and Kuhlmann, 2004, p. 11).

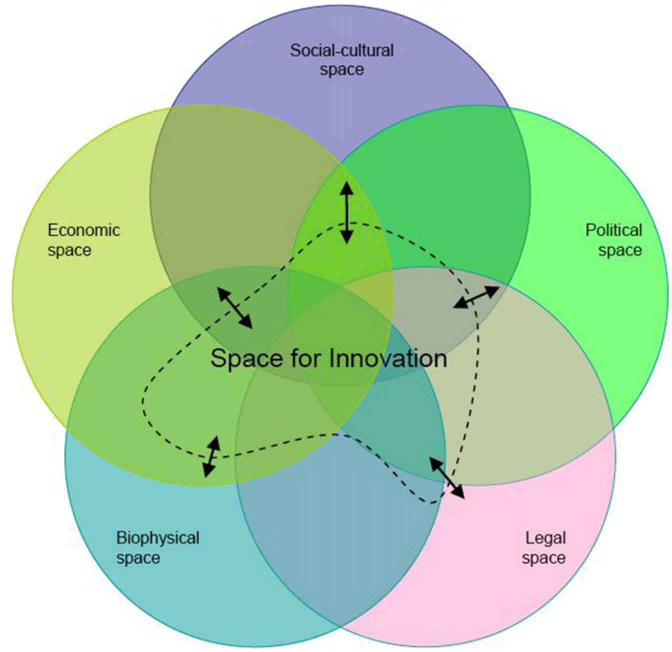

Fig. 1. Subsystems that constitute space for innovation.

A second fundamental premise for analysing local space for innovation is to study the interactions of subsystems across different scales and levels of analysis (spatial dynamics) through time (temporal dynamics) (cf. Cash et al., 2006). In terms of designing policy for community-based biofuel production and use, this implies addressing all relevant levels of policy influence that enhance or constrain local space for innovation, from international biofuel sustainability criteria to local customary laws and practices (Giller et al., 2008). Temporal dynamics require that innovations should be approached and studied as dynamic processes (Hekkert et al., 2007, p. 414). Although Fig. 1 presents a rather static image of space for innovation and suggests that innovations can only be sustainable when all subsystems overlap, this is often not the case. Space for innovation is generally found within one of the subsystems, complemented by or triggering change of space in other subsystems. For example: "[N]ew laws, entry of new actors, and other events change [...] [space for innovation] over time" (Hekkert et al., 2007, p. 417).

In sum, the dynamics and interactions between different subsystems across different scales and levels of analysis through time can both constrain or enhance (local) space for innovations, and in doing so, influence the extent to which innovations can contribute to sustainable and dynamic development (cf. Leeuwis and Aarts, 2011).

Most of the empirical data for this study were gathered from Nhambita community in Gorongosa District, Sofala Province, Mozambique (Fig. 2). Nhambita was chosen for this study as it is one of the few communities where smallholders still grow jatropha. Moreover, jatropha trials were established with the support of the Envirotrade project (see Section 3) and an oil-seed

[2] Due to the poor quality of distributed jatropha seed and a lack of agronomic knowledge on crop management, many trees died. The few farmers that produced jatropha grain failed to sell it as there were no organized markets and supply chains (Schut et al., 2010c, p. 5152).

[3] Selected crops are jatropha and coconut for biodiesel, and sugarcane and sweet sorghum for the production of bioethanol (Government of Mozambique, 2009, p. 14).

Fig. 2. Nhambita community in Gorongosa District, Sofala Province, Mozambique.

press was provided by the Ministry of Energy, creating a unique enabling environment for community-based biofuel production and use. Nhambita community is part of the Chicare *Regulado* (traditional authority) and accommodates around 85 households.

To reach our objectives, we present various forms of data. As innovation trajectories are dynamic and need to be understood through time, we firstly provide background information on the introduction and performance of jatropha in the community. This information is based on field visits, semi-structured interviews with Envirotrade staff, extensionists and farmers from the community, complemented with secondary data analysis of scientific papers, reports, presentations and policy documents. Secondly, we present a combination of data to explore existing farming strategies in Nhambita. To get an idea about the local dynamics and heterogeneity of farming in the community, three highly contrasting case-study farms were selected and repeatedly visited and interviewed between July 2009 and July 2010. Only one of the farms grows jatropha; nevertheless, understanding reasons for not allocating resources to biofuel production is equally important when one is analysing space for innovation. In-depth interviews were conducted at the homestead of the households. The questionnaire that guided those interviews can be found in Bos et al. (2010). GPS was used to plot and measure the farmers' fields where possible. A transect-walk allowed us to better understand the geographical spread of farming activities as compared with the biophysical diversity in the area. We analyse the case-study farms by drawing on existing literature on farming strategies and agricultural statistics from Mozambique and other SSA countries. Thirdly, we analyse the potential space for localized use, or for local marketing of biofuels. In line with other studies (cf. van Eijck and Romijn, 2008), we also explore the potential for non-energy applications, such as the use of jatropha oil for local soap production and the potential for organic fertilizer production. Semi-structured interviews were used to collect data on energy consumption by households and the Envirotrade project. Interviews with shopkeepers on local prices and consumption patterns of fuel and oil-based products enabled us to develop scenarios for the local production and use of biofuels. Lastly, two of the authors of this paper actively participated in the policy debate on biofuel sustainability in Mozambique. Between December 2008 and November 2010 they supported an inter-ministerial working group in developing a biofuel sustainability framework for Mozambique. This work allows us to describe the evolving political and legal environment, which is necessary to comprehend the dynamic context in which biofuel developments in Mozambique take place.

3. Setting the scene: Nhambita and Envirotrade

Nhambita community is located in the buffer zone of Gorongosa National Park (NP), one of Mozambique's most biodiverse areas, and a famous tourist destination. The area can be classified as savannah (or miombo) woodland, which is generally found on nutrient poor and acidic soils (Campbell et al., 1996; Frost, 1996) with low organic content (Ryan, 2009). The area is a previous war front, and this has greatly impacted the social structures in the communities. After the war in 1992, the return of displaced people led to a major population increase in the area (University of Edinburgh, 2008, p. 53). Although a peace treaty was signed, the situation for the communities in the area remained difficult. Commercial agricultural production (mainly cotton) had collapsed and there was little or no access to medical services, education, employment, capital or markets. As communities relied heavily on the area for agriculture and charcoal production, this resulted in increased pressure on Gorongosa NP.

The majority of the approximately 1100 households in the Chicare *Regulado* depend on forest resources and agriculture for their livelihoods. Their main sources of income derive from selling agricultural and animal products, and locally made products such as bricks. Farmers use shifting cultivation and crop rotation to maintain agricultural productivity. Due to the exodus of the local population during the war, most land was left fallow for a long time, resulting in relatively fertile soils when people started to return in the 1990s (University of Edinburgh, 2008, p. 69).

Commonly grown crops in the community are maize, cassava, sorghum, pigeonpea, and various fruits and vegetables. The majority of households own more than one plot (referred to as *machambas* or *dimbas*). *Machambas* are generally located near the homestead, or on land further away from the homestead (outfields). Plots located near the various small rivers and streams in the area are called *dimbas. Dimbas* are highly valued as they are generally more fertile than *machambas* and allow for production in the dry season. *Dimbas* are often used for high-value cash crops, such as vegetables. Agriculture in the area is predominantly rainfed, with mean annual rainfall of 850 mm of which 82% falls between November and March (Ryan, 2009, p. 31). Agricultural production follows a seasonal cycle wherein crops such as maize and sorghum are sown after the arrival of the rains (November–December). Agricultural extension provided by government – as in other places in Mozambique – is almost non-existent (Coughlin, 2006, p. 30).

The majority of permanent wage jobs in Nhambita community are provided by the Envirotrade project. Envirotrade is a

Mauritius-based company that has developed a business model for selling carbon offsets generated through involving smallholder farmers in conservation management and reforestation activities (www.envirotrade.co.uk). It is one of the few projects in Africa where smallholder farmers receive payments for the conservation of carbon under a voluntary payment scheme. Under the Gorongosa Community Carbon Project, the Envirotrade project offers farmers different agro-forestry contracts, such as planting trees to improve soil quality through nitrogen fixation, the conservation of woodlots and non-burning of fields. In the case of planting trees, the project provides the trees to farmers and monitors their condition twice a year. Farmers receive an annual remuneration, spread over seven years, for maintaining the planted trees.

Besides the agro-forestry contracts, the project supports the establishment of microbusiness associations such as a carpentry and tree nurseries. The project has also established rural community committees, responsible for monitoring the forest management activities. So-called community trust funds are used to initiate and manage community projects.

Photo 1. Mostly dead jatropha plants in the communal jatropha trial in Nhambita community.
Photo taken by M. Schut in July 2009.

4. The introduction of two new crops in Nhambita community

One of the principal objectives of the Envirotrade project is to promote sustainable land use practices and provide alternatives to shifting cultivation and the opening up of new *machambas* using the slash-and-burn method. Besides providing income through the different agro-forestry contracts, the project stimulates the production of cash crops for sale on local markets (Envirotrade, 2006, p. 5). For the purpose of this study, we describe the recent introduction of two crops in the community: pigeonpea and jatropha. Both crops were introduced more or less around the same time; allowing for comparative analysis with regard to their relative performance and adoption in the community.

4.1. Pigeonpea

Between November 2004 and January 2005, Envirotrade initiated a programme stimulating the intercropping of pigeonpea (*Cajanus cajan* (L.) Millsp.) (Envirotrade, 2006, p. 10). The objective was to reduce the opening up of new *machambas* by regenerating soils of existing *machambas*. This would consequently reduce deforestation and provide farmers with a new cash crop. Each household received five kilograms of seed, to be reimbursed after the first harvest. Pigeonpea is a perennial leguminous multi-purpose crop that can produce grain for human consumption, fodder for supplementary livestock feed and mulch or green manure for soil fertility maintenance (Agyare et al., 2002). The crop has a deep rooting system and can as a result improve soil fertility through more efficient nutrient cycling through leaf litter production and biological nitrogen fixation (Giller, 2001). Pigeonpea is easy to establish from seed and grows well under the combined stresses of drought and poor soil fertility (Agyare et al., 2002, p. 198). Moreover, pigeonpea grain is highly nutritious and can be stored for a long time. During our fieldwork we observed that pigeonpea is used for intercropping by the majority of farmers in Nhambita community. Pigeonpea is used for household consumption and sold as a cash crop.

4.2. Jatropha

Following the government's promotion of jatropha, a communal jatropha trial in Nhambita community was established by the end of 2005. Between February and April 2006, the trial increased to around 4 ha. The jatropha grew extremely well during the first growing season, and, between May and July 2006, 250 farmers from the area expressed an interest in planting jatropha. During that time, the first grain was harvested from the jatropha trials (Envirotrade, 2006).

When the first pruning was needed, little agronomic knowledge existed on how and when to prune effectively. From our interviews we learned that during the first pruning all branches were cut off, leaving just the main stem. Subsequently, Envirotrade was advised to do a second pruning, cutting back all plants to knee height. The second pruning was followed by a humid period, after which the majority of plants started rotting and died (Photo 1). Samples were sent for analysis to the Forest Faculty of Pietermaritzburg University in South Africa. As the samples did not arrive fresh, they could only be tested for bacterial infections, and they tested negative. The plants could not be tested for viral infections and fungi, which according to Envirotrade's operations manager are likely to have affected the jatropha.

The site where the jatropha trial had been established was left fallow for a long time, and soil quality and fertility status – although we did not have the resources to analyse soil samples – appeared to be reasonable.

5. Farming strategies in Nhambita community

In Nhambita community, farming strategies are centred around crop production and off-farm activities. Farming strategies are not homogeneous as resource allocation varies between households of different social classes, according to their objectives and factor constraints (Tittonell et al., 2005). Our method for describing the three highly contrasting case-study farms and their interdependencies is inspired by farming systems analysis (cf. Tittonell et al., 2005; van Wijk et al., 2009; Giller et al., 2011). As it is not our aim to describe the farming systems in detail, we use a simplified approach to highlight the main features that influence allocation of resources at both farm and community level, and how that may affect community-based biofuel production.

5.1. Exploring heterogeneity: three case-study farms

The 85 farm households in Nhambita community were roughly divided into three categories; high, medium and low resource endowed.[4] This stratified approach to categorizing farms

[4] In relation to assets representing classical wealth indicators such as land size and livestock ownership (Tittonell et al., 2009), or labour availability, use of fertilizer and hiring temporary labour (Mather et al., 2008).

according to resource endowment is often used in studies on farming systems (Tittonell et al., 2009; van Wijk et al., 2009; Zingore et al., 2009). On the basis of the three categories, Envirotrade's senior extensionist assisted us in identifying five farm households per category. After exploratory visits to farm households from the three categories, one case-study farm per category was selected. For the purpose of the study, we chose to select three highly contrasting case-study farms. In the group of high resource endowed farm households, a farmer growing jatropha was purposively sampled, which is justifiable considering the nature of this study (cf. Russell Bernard, 2006, pp. 189–190). In the groups of the low and medium resource endowed farm households, none of the farmers was growing jatropha.

5.1.1. Household 1: high resource endowed

The male head of this household is a well-known farmer in the community and is involved in many activities. The household consists of twelve members, of which eight provide labour for on- and off-farm activities. The head of the household works as a driver for Envirotrade, and his wives and labourers run the farm. The total farm size is 15.8 ha, divided into 10 fields. The *machambas* are located around the homestead (1.4 ha) and an outfield in Themba (2.4 ha). The household owns eight *dimbas* (12 ha), of which some land was bought. Near the homestead the household grows food and cash crops. On the *dimbas*, fruits and vegetables are produced. Main food crops are maize, cassava, sorghum and pigeonpea, the excess of which (except sorghum) is sold. Important cash crops are beans, sesame and bananas.

To manage soil fertility, crops are rotated, and crop residues are incorporated into the soil during land preparation. During the last growing season, the farmer applied small amounts of synthetic fertilizer (3 kg) to the vegetables. The fertilizer was bought in Chimoio (approximately 150 km from the community). Goat manure is gathered and also applied to the vegetable garden. Seeds used are mainly local varieties, although the farmer bought an improved maize seed variety in Chimoio last year. During the last cropping season, the crops were affected by pests, but no agro-chemicals were applied to manage them.

On the homestead *machamba*, jatropha is intercropped with pigeonpea (0.2 ha jatropha, 0.2 ha pigeonpea). The jatropha was planted in 2005 using seed provided by Envirotrade. The first jatropha grain has been harvested, although limited in quantity (half a bucket). As there is currently no organized market for jatropha grain, the household is still uncertain about what to do with it. One of the household members explained that jatropha was planted as an experiment for a maximum period of five years. If – by that time – there was no market on which to sell the jatropha grain, they would stop investing land and labour in it. In August 2009, the jatropha appeared to be in good condition. It had leaves and fruits, unlike the remaining jatropha in the communal trial (see Photo 1). In July 2010, we observed that the *machamba* had not been actively managed in terms of weeding or pruning, resulting in bad ramification and limited fruit production. We could see that fruits had not been harvested (causing dehiscing), as confirmed by one of the household members.

The household owns a substantial number of goats and poultry but no cattle. The livestock are mainly for home consumption, but occasionally sold. Additional income is derived from agro-forestry contracts with Envirotrade. The head of the household is involved in one of the microbusiness nursery associations and is a shareholder in the maize mill. Occasionally, the household receives remittances in kind, such as rice from family members living in Beira, the capital of Sofala Province. The household's main expenditures are on soap, cooking oil, salt, sugar, fish and school requisites for the children. Moreover, money is being spent on milling, buying mobile phone credits, and occasionally improved seeds and fertilizer. Bush clearing, ploughing, planting, weeding and harvesting are done manually. External labour is hired and paid for both in cash and in kind.

5.1.2. Household 2: medium resource endowed

The male head of the household is a war veteran (for which he receives a monthly government pension) who settled in Nhambita community after Mozambique's armed struggle. The household consists of four members, all contributing labour to the household's activities. The household has three agro-forestry contracts with Envirotrade, and the head of the household works as an Envirotrade employee. His salary is being invested in constructing a stone house, which was almost finished at the time of our visit in July 2010.

On the *machamba* nearest to the homestead, the household grows maize and pigeonpea (1 ha). On the other homestead *machamba* (3 ha), sorghum, pigeonpea and maize are grown. Mangos, sesame, pineapple, cashew, tomatoes and sweet potato are planted around the homestead. Labour constraints, especially for weeding, keep the household from cultivating all available land. The household does not apply fertilizer but keeps residues on the fields. They mainly use local seed varieties, although they used an improved pigeonpea variety that was distributed by Envirotrade. The household owns one *dimba* (estimated at 0.5 ha) which is ploughed first. When production is good, excess sorghum and maize are sold. Mangos are used to pay day labourers who plough and weed the fields.

The household owns about 30 chicken, two ducks and two goats, mainly for home consumption. Manure is not applied to the fields and no agro-chemicals are being used. The major expenses of the household are cooking oil, soap, salt, petroleum for lighting, and milling of maize and sorghum. No remittances are received or sent.

The household does not grow jatropha. The head of the household believes that jatropha does not grow well in the area. He first wants to see jatropha yield well, before he would start growing it.

5.1.3. Household 3: low resource endowed

This household consists of five members, four of whom contribute labour to the household activities. The family owns a *machamba* near the homestead (0.5 ha) and a *dimba* (estimated around 1 ha). The male head of the household is responsible for the work on the *dimba* as it is more clayey and therefore harder to work. His wife mainly works on the homestead *machamba* where they intercrop maize and sorghum. On the *dimba* they grow maize, sorghum and some vegetables. The *dimba* is the most important field for the household. Pigeonpea is planted around and randomly in all fields. They have some mango and papaya trees and brew some beverages for home consumption.

The complete yield is used for household consumption. Two household members work two or three days per week as labourers for other farmers, the rest of their available time they invest in their own fields. The household has one agro-forestry contract with Envirotrade for planting indigenous trees. Last year, one of the household members worked temporarily for Envirotrade as a construction worker.

Improved seed varieties, fertilizers or agro-chemicals are not used, and no livestock is owned at the moment. Main expenditures are on milling, and buying salt and soap. The household does not receive any remittances.

The household has only recently heard about jatropha, when it was planted in the community. They know it can be used as fuel, but that the crop is difficult to grow. If others started growing it, they would also be interested. At the time of our last visit to the

Table 1
Summary and comparison of the three case-study farms.

Household	1	2	3
Resource endowment	High	Medium	Low
Household size (persons)	12	4	5
Household members contributing labour to household	8	4	4
Fields (#)	10	3	2
Total farm size (ha)[a]	15.8	4.5	1.5
Number, location and size of fields	1 homestead *machamba* (1.4 ha), 1 outfield *machamba* (2.4 ha) and 8 *dimbas* (12 ha)	2 homestead *machambas* (4 ha) and 1 *dimba* (0.5 ha)	1 homestead *machamba* (0.5 ha) and 1 *dimba* (1 ha)
Main food/cash crops	Maize, cassava, pigeonpea, sorghum and sesame	Maize, sorghum, and pigeonpea	Maize, sorghum and pigeonpea
Fruits, vegetables and other crops	Bananas, papaya, cashew, sesame, sweet potato, tomato, beans, onion and cabbage	Mangos, pineapple, cashew, sesame, sweet potato and tomato	Mango and papaya, tomatoes, onion and cabbage
Biofuel crops	Jatropha (0.2 ha)	–	–
Livestock	Goats, ducks, chickens and turkeys	Goats, ducks and chickens	–
Apply synthetic fertilizer	Yes (3 kg to vegetables)	–	–
Apply manure	Yes (to vegetables)	–	–
Use improved seed	Yes (maize)	Rarely	–
Envirotrade agro-forestry contract(s)	Yes	Yes	Yes
Received remittances (money/in kind)	In kind: rice	–	–
Off-farm income			
• Day labourer for other farmers			X (2–3 days per week)
• Government pension		X	
• Envirotrade	X (salaried employment)	X (salaried employment)	X (occasionally as labourer)
Main expenditures	Cooking oil, soap, salt, sugar, milling, mobile phone credit, paying labourers, fertilizer, improved seeds	Cooking oil, soap, salt, milling, petroleum for lighting	Milling, soap and salt

[a] A combination of field-size measured using GPS and estimations made together with the farmers.

community in July 2010, the household had moved from the research area to an unknown location.

5.2. Analysis of case-study farms

The heterogeneity found in our three case-study farms is summarized in Table 1. Smallholder agriculture in Nhambita is dominated by rain-fed maize, sorghum, cassava and pigeonpea production. Important cash crops are sweet potato, beans and sesame. Only the high resource endowed household is growing jatropha as an experiment. Amongst the main expenditures for all interviewed households were milling, buying salt and soap.

As commonly seen in Mozambican smallholder agriculture, there exists a relationship between resource endowment, access to labour, the amount of land owned and cultivated, possession of livestock and wealth (Mather et al., 2008). Such patterns have also been observed in other SSA countries such as Kenya (Tittonell et al., 2005) and Zimbabwe (Zingore et al., 2007). High to medium resource endowed households often have access to permanent sources of off-farm income (e.g. salary or pension) and compensate lack of household labour by hiring in labour which they pay for in cash or in kind. Moreover, high resource endowed households can afford inflows of inputs, such as fertilizers or improved seeds, and use animal manure to enhance agricultural productivity. On the other side of the spectrum, low resource endowed farm households are faced with multiple constraints, which include small farm size, competing demands for labour, and lack of livestock, manure and cash to buy inputs. We must emphasize that smallholders in Mozambique typically do not use, and do not have easy access to, agricultural inputs. According to a national survey conducted in 2007, only 4% of Mozambican farmers use fertilizers (FAO/WFP, 2010, p. 13). The households that do have access to nutrient inputs tend to apply manure or fertilizer to high-value cash crops such as vegetables. Another significant difference between Mozambique and other SSA countries is that household livestock assets are relatively low (Mather et al., 2008, p. 10). Cattle in particular are not to be found in vast parts of the country, and in Nhambita none of the households owns cattle. The main reason is the lack of control of tsetse-fly, tick-borne and foot-and-mouth diseases (FAO/WFP, 2010, p. 17).

Access to land does not seem to be a constraining factor for the expansion of crop production. TIA (*Trabalho de Inquérito Agrícola*—Mozambique Agricultural Survey, 2002) found that: "85% of households declared that it was 'easy to obtain additional land' in their village" (Mather et al., 2008, p. 21). In Nhambita, some scarcity was mentioned for land in the *dimbas*, which are the more fertile and productive soils. *Dimbas* are generally used for the production of cash crops such as vegetables, although the low resource endowed household indicated that they grew food crops in the *dimba*.

In the absence of cattle, and no apparent land scarcity, mobilizing and allocating labour to different on- and off-farm activities – especially during peaks in the labour calendar – seems crucial in Mozambican smallholder agriculture. In the next section, we further explore how this affects the potential for jatropha production within the different case-study farms.

5.3. Land and labour requirements vis-à-vis jatropha production

As maize is the staple food crop in the community, we calculate maize production and consumption as an indicator of food self-sufficiency within the three case-study farms. Food-crop yields in Mozambique are low compared with other SSA countries (Tschirley and Weber, 1994). Based on different literature sources we estimate average annual maize yields for *machambas* and *dimbas* in Nhambita community at 500 kg ha^{-1}, using local seeds and no irrigation or nutrient inputs (Tschirley and Weber, 1994; Howard et al., 2003; FAO/WFP, 2010). Assuming post-harvest losses of 12% or 60 kg ha^{-1} (FAO/WFP, 2010, p. 23) and a maize seed requirement of 25 kg ha^{-1} (FAO/WFP, 2010, p. 24), 415 kg ha^{-1} become effectively available to meet household food

Table 2
Land and labour dynamics versus food self-sufficiency calculated for the three case-study farms.

Household	**1**	**2**	**3**
Resource endowment	High	Medium	Low
Household (hh) size (persons)	12	4	5
Contributing labour to household (persons)	8	4	4
Food requirement (kg maize hh^{-1} $year^{-1}$)	1200	400	500
Land requirements			
Field size needed to achieve maize self-sufficiency (ha)	2.89	0.96	1.20
Total farm size (ha)	15.8	4.5	1.5
• *Machambas* (ha)	3.8	4	0.5
• *Dimbas* (ha)	12	0.5	1
Percentage of total farm size needed to achieve maize self-sufficiency (%)	18	21	80
• Percentage of *machamba* needed to achieve maize self-sufficiency (%)	76	24	100
• Percentage of *dimba* needed to achieve maize self-sufficiency (%)	0	0	70
Labour requirements			
Land:labour ratio[a]	2.0	1.1	0.4

[a] Land:labour ratio calculated as total farm size divided by number of household members contributing labour to household (Zingore et al., 2011).

requirements. On average, annual maize consumption per individual was estimated at 100 kg, on the basis of estimates of actual maize consumed by farmers in a typical diet dominated by maize in Sub-Saharan Africa (Zingore et al., 2009, 2011). We use this figure as an indicator for calculating maize requirements at household level, although we understand that farmers have a more varied diet. In our calculations we did not include additional food sources such as remittances or food aid.

The high and medium resource endowed farmers need around 20% of their total farm size to achieve household maize self-sufficiency (Table 2). Production can be achieved within the *machamba* field size, leaving additional space on the *machambas* and the *dimbas* for cash crop production (taking potential labour constraints into account). The low resource endowed farm needs 80% of its total farm size to produce sufficient maize for household consumption. Other than for the high and medium resource endowed household, part of the *dimbas* is needed to achieve maize self-sufficiency; this matches the assertion by the low resource endowed household that maize and sorghum are grown in the *dimba*. TIA data from 2005 moreover indicate that high resource endowed households are more resilient in terms of their household food reserves and have far less difficulty feeding their families throughout the year as compared with low resource endowed households (Mather et al., 2008, p. 19). High and medium resource endowed households are likely to produce excess food crops, used for sale or to pay labourers.

The land:labour ratio (Table 2) can be used as an indicator of the effective cultivation capacity of land per household member contributing labour to the household's activities. The ratio is influenced by the amount of labour available within the household, either increased by hiring in labour, or reduced by hiring out labour, demonstrating important labour synergies at community level. Crop production on wealthy farms is enhanced by labour supplied by poor farmers. Subsequently, poor farmers who struggle to achieve food self-sufficiency benefit from the excess maize production at the community level in return for the labour they sell to wealthy farmers (Zingore et al., 2009). Demands for labour are not equally distributed throughout the year as labour is especially scarce just before the rainy season (land preparation) and during the rainy season (weeding). As many low resource endowed household – during this time of the year – have run out of food reserves from the previous harvest, they are 'forced' to sell some of their labour to meet their food requirements. Consequently, this reduces the area cultivated, crop management – and consequently – yields on their own farm (cf. Zingore et al., 2009, p. 58).

Relating our findings on land and labour requirements to our case-study farms and the potential for jatropha production, we conclude that the high and medium resource endowed farm households have *machamba* available for growing jatropha, without negatively affecting food self-sufficiency within the household. Although these households produce excess food crops to pay labourers or to sell on the market, allocating small parts of *machamba* to jatropha is possible, as shown by the high resource endowed case-study household. The feasibility of jatropha cultivation within the low resource endowed household is highly questionable as they need all their *machamba* and a large part of their *dimba* to achieve food self-sufficiency.

Demands on labour are high, especially during peaks in the labour calendar. As jatropha is a perennial crop, labour for land preparation and planting is only required preceding the first growing season. Jatropha can be planted shortly before the beginning of the rainy season. Especially after the first growing season, jatropha is fairly drought-tolerant. In the absence of water, the plant goes into dormancy and sheds its leaves, but will grow once water becomes available (Flemming Nielsen, FACT Foundation, personal communication). Labour demands for weeding are similar to weeding of other crops, although increased canopy cover (depending on planting distance and pruning) will decrease labour requirements over time. Jatropha pruning is preferably done during the dry season when labour demands for other crops are low. As jatropha does not drop its fruits, harvesting the jatropha grain can be somewhat postponed until after food crops have been harvested. Leaving the fruits on the trees will reduce water content in the grain, which is preferable when its oil is to be extracted. However, leaving the fruits on the tree too long will result in dehiscing and loss of the grain, as we saw at the case-study farm growing jatropha. Under the current conditions, investing labour in jatropha production will be particularly difficult for the low resource endowed household who already face labour constraints. For the high resource endowed household, it is not so much labour constraints as prioritizing the allocation of labour to different crops and activities compared with their relative revenues and benefits.

6. Potential for local market development

We focus on analysing the potential for localized use or for local marketing of biofuels, as this seems less sensitive to 'outside' distortions such as fluctuating crude oil prices (cf. Practical Action

Table 3
Overview of fossil fuel usage in Nhambita community by households and the Envirotrade project.

Household level	Potential for PPO use	Average consumption at community level
Households (n=85)	Petroleum for lighting	21.3 l petroleum week^{-1}
Envirotrade and microbusiness associations	**Potential for PPO use**	**Average consumption**
Envirotrade project	Generator	200 l diesel week^{-1}
Carpentry association	Generator	25 l diesel week^{-1}
Maize mill association	Maize mill	10 l diesel week^{-1}

Consulting, 2009). The fact that the local fuel prices in Nhambita community did not change between September 2009 and July 2010 (US$2.10 l^{-1} for petroleum),[5] vis-à-vis a 24% increase in fossil fuel prices during that same period at fuel stations, supports this assumption. Local market development is moreover in line with the Mozambican government's objectives to contribute to local energy security and stimulate socioeconomic development in rural areas.

Analysing the current use of fossil fuels and oil-based products in Nhambita community enabled us to develop three scenarios that provide a basic idea of the scale of jatropha production needed to partly replace fossil fuels with pure plant oil (PPO) or to locally manufacture oil-based products such as soap. As jatropha press-cake and fruit coats are rich in nutrients (Jongschaap et al., 2007, p. 16), we calculated the potential for organic fertilizer production using jatropha press-cake within each of the three scenarios.

6.1. Current consumption of fossil fuels and oil-based products

The majority of the 85 households in Nhambita use petroleum lamps for lighting as the community is not connected to the electricity grid. Petroleum can be bought at the local shops for US$0.53 per 250 ml, which is, according to the local shop owners, the average weekly household consumption. The lamps and petroleum form an important commodity for the local shops. However, the locally sold fuel is expensive, amounting to US$2.10 l^{-1} as compared with US$0.88 l^{-1} at the petrol station in September 2009.

The Envirotrade project has a diesel generator to supply their offices with electricity. The average consumption of the generator is 200 l diesel week^{-1}. The generator is also used by the carpentry association (25 l diesel week^{-1}). The maize mill microbusiness association uses a diesel engine (10 l diesel week^{-1}) to power their mill (Table 3). We decided not to include the fuel usage by Envirotrade's vehicles and motor cycles. Diesel for the generators is bought in Chimoio for US$0.88 l^{-1}.

The analysis of the three case-study farms (Table 1) revealed another potential application of PPO as all interviewed households indicated that buying soap is amongst their main expenditures. An average household of five persons uses two bars of soap per month, corresponding to US$1.05 (US$0.53 per bar[6]). As jatropha-based PPO is suitable for manufacturing soap, there is potential for local soap production in Nhambita community. Furthermore, local soap production could be seen as an opportunity to establish a new microbusiness association.

6.2. Scenarios for local use of jatropha PPO and organic fertilizer production

To keep our scenarios as realistic as possible, we have used data from FACT Foundation, gathered at a community-based jatropha project in Cabo Delgado Province, Mozambique. The data show that approximately 5 kg of jatropha grain are needed to produce locally 1 l of PPO (similar findings were found by van Eijck and Romijn, 2008, p. 314). Such a ratio more or less corresponds with a jatropha grain oil content of 30% and a press efficiency of 60%, using a specific gravity of 0.92 kg l^{-1} for jatropha oil.[7] On the basis of average rainfall data from the Nhambita region (850 mm yr^{-1}) and medium soil fertility status, jatropha grain yields were estimated at 1250 kg ha^{-1} yr^{-1} (de Jongh, 2010). Within each scenario, we compare the value of the jatropha if processed and used locally vis-à-vis the value of the jatropha grain if sold for US$0.11 kg^{-1} on the market (Flemming Nielsen, FACT Foundation, personal communication). Table 4 summarizes and compares the scenarios.

6.2.1. Scenario 1: PPO for lighting

Jatropha grain contains viscous oil with few other components than oil, fats and carbohydrates, which makes it well suited for burning (Jongschaap et al., 2007, p. 15). To supply all households in our study area (n=85) with 250 ml petroleum week^{-1}, 1105 l PPO yr^{-1} would be needed annually.[8] Producing this quantity would require 5648 kg jatropha grain yr^{-1}, equivalent to 4.5 ha based on a jatropha grain production of 1250 kg ha^{-1} yr^{-1}. This equals a value of US$2321 yr^{-1} if the equivalent of petroleum is bought at local shops for US$2.10 l^{-1}. If the PPO is used locally for lighting, the value of the jatropha would be US$514 ha^{-1}.

However, there are some technical issues to bear in mind. Jatropha oil will not burn easily in regular oil lanterns because of its high viscosity and low capillary effect. Low-tech lamps such as the *Binga Lamp* could serve this purpose better (Flemming Nielsen, FACT Foundation, personal communication). Further research is needed to investigate whether indoor burning of jatropha PPO is actually healthier than using petroleum or other fossil fuels for lighting.

6.2.2. Scenario 2: soap production from PPO

To produce 1.27 kg of soap, 1 l PPO, 0.35 l water and 150 g caustic soda are needed (de Jongh, 2010, p. 77). One bar of soap weighs around 0.45 kg,[9] roughly indicating that at least two bars of soap can

[5] To convert prices from the Mozambican Metical (MZN) to US Dollar (US$), we have used the average exchange rate during the time the research was conducted (between 1 July 2009 and 30 June 2010). According to www.oanda.com, the average exchange rate during this period was MZN1 to US$0.035.

[6] Due to the conversion of prices from MZN to US$ and rounding off of numbers, small inconsistencies may occur.

[7] Using these percentages and specific gravity showed that 5.11 kg jatropha grain are needed to produce 1 l PPO; this is the figure that we used in our calculations. Corresponding author can be contacted for more detailed formulas.

[8] We assume here that 1 l PPO has the same energy content as 1 l petroleum. In the literature, all we could find was that the energy content of PPO is about 4–5% less per volume as compared with fossil diesel (de Jongh, 2010, p. 62).

[9] Soap bars weighed by FACT Foundation in Bilibiza, Cabo Delgado.

Table 4
Different scenarios for community-based jatropha production, use of PPO and the production of organic fertilizer.

Scenarios	*Scenario 1: Provide 85 households with 250 ml PPO weekly*	*Scenario 2: Provide 85 households with two soap bars monthly*	*Scenario 3: Replace 50% of the annual diesel consumed by Envirotrade, the carpentry and the maize mill with PPO*
Required amount of PPO (l yr^{-1})	1105	1020	6110
Required amount of jatropha grain (kg yr^{-1})	5648	5213	31,229
Required land for jatropha production (ha yr^{-1})	4.5	4.2	25.0
Total value if sold for US$0.11 kg^{-1}	593	547	3279
• Value ha^{-1} (US$)	131	131	131
Total value if used locally (US$)	2321	1071	5346
• Value ha^{-1} (US$)	514	257	214
Organic fertilizer production per scenario			
Seed-cake organic fertilizer (kg yr^{-1})	4631	4275	25,608
Seed-cake organic fertilizer per household (hh) (kg hh yr^{-1})	54.5	50.3	301

be manufactured from 1 l PPO. Providing all households ($n=85$) with two bars of soap per month would require 1020 l PPO yr^{-1}. The required 5213 kg jatropha grain yr^{-1} can be produced on 4.2 ha. The produced soap represents a total value of US$1071 yr^{-1} compared with soap sold locally for US$0.53 per bar. If used locally, the value of the jatropha per hectare would be US$257.

The social–cultural acceptance of buying and using locally produced soap (e.g. smell, colour and foam) requires attention, although jatropha soap is generally whiter – and therefore considered of a higher quality – than the brown soap bars locally available (Flemming Nielsen, FACT Foundation, personal communication). Another point of attention is that the local availability of caustic soda could be problematic.

6.2.3. Scenario 3: PPO application in generators

The conversion of diesel engines to (partly) run on jatropha PPO is only attractive when regular and sufficient PPO production can be guaranteed. To generate power for Envirotrade, the carpentry and the maize mill, 12,220 l diesel yr^{-1} is needed.[10] If 50% of the consumed diesel (6110 l yr^{-1}) was replaced by PPO, 31,229 kg jatropha grain yr^{-1} would be needed, and this requires growing 25 ha of jatropha. Compared with diesel bought for US$0.88 l^{-1} at the petrol station, 6110 l PPO equals a total value of US$5346 yr^{-1}. In this scenario, the value of the jatropha per hectare would be US$214.

6.2.4. Production of organic fertilizer

The by-products of jatropha such as fruit coats and press-cake can be used as organic fertilizer. The press-cake in particular is nutrient rich and therefore very suitable as a fertilizer (Jongschaap et al., 2007, p. 16, 28).

One kilogram of jatropha fruit (dry weight) can roughly be divided in 0.7 kg grain and 0.3 kg fruit coat (Jongschaap et al., 2007, p. 14). With an oil content of 30% and a press efficiency of 60%, 1 kg of jatropha grain would provide 0.18 kg PPO or 0.20 l PPO (PPO weighs 0.92 kg l^{-1}). The remaining 0.82 kg press-cake can be used as organic fertilizer (Jongschaap et al., 2007, p. 16). One ton of press-cake contains approximately 51 kg of nitrogen (N), 18 kg of phosphorus (P) and 13 kg of potassium (K) (de Jongh, 2010, p. 84). The equivalent of synthetic fertilizer can be calculated on the basis of the press-cake nutrients. However, as nutrients in synthetic fertilizer are much more available for crops than nutrients in jatropha press-cake, this does not allow for a fair comparison.

As fertilizers are not commonly used or available in Nhambita community, applying organic fertilizer could boost crop production. Moreover, applying the fruit coats and other residues on the fields will increase the organic matter in the soil and induce higher retention of water and nutrients, and reduce the growth of weeds and consequently labour demands for weeding.

6.3. Analysis of the potential for local market development

Table 4 provides an overview of the potential local market for PPO use in Nhambita and the amount of land needed to fulfil each scenario. Based on available knowledge and experiences, we think we have been quite conservative in determining jatropha grain yields, oil content (30%) and press efficiency (60%). We want to emphasize that the 'total values' and 'values ha^{-1}' in US$ in Table 4 should not be interpreted as 'revenues.' Calculating revenues would require the analysis of the total amount of labour, land and inputs needed to produce and process jatropha as compared with e.g. buying petroleum or industrial soap locally, and allocating the same labour, land and inputs to other on- or off-farm activities. Although jatropha is known to produce grain in the first and second year, yields of 1250 kg ha^{-1} yr^{-1} will most probably be achieved from the third or fourth growing season onwards. Furthermore, whether such yields can be considered realistic depends, on biophysical conditions and crop management. If not used, processed and marketed locally, the market price paid for jatropha grain – at the time of the research – was approximately US$0.11 kg^{-1}. This price will fluctuate, as it is, highly dependent on fossil fuel prices and regional demand and supply (Flemming Nielsen, FACT Foundation, personal communication). When using the market price of US$0.11 kg^{-1} in our scenarios, the value of jatropha grain per hectare equals US$131, most likely from the third growing season onwards, when yields of 1250 kg ha^{-1} yr^{-1} can be expected. How this relates to revenues from producing other cash crops that can be harvested annually, using a similar amount of land, labour and inputs, requires further research.

Of the three scenarios, the production of PPO for lighting or local soap manufacture seems the most realistic option in the short term. It requires the smallest amount of land for jatropha production and, besides testing oil lamps and developing soap-making techniques, no costly investments are required as an oil-press is already available to the community. Moreover, the potential (added) value per hectare is relatively high as compared with selling the grain for a market price of US$0.11 kg^{-1}. Within the PPO for lighting scenario in particular, the value per hectare is almost four times higher, mainly because of the high local prices

[10] Calculations based on five working days per week and 52 working weeks per year.

for petroleum. Combined, scenarios 1 and 2 produce around 100 kg organic fertilizer $hh^{-1}\,yr^{-1}$. This could increase agricultural productivity as currently no fertilizers are used by the majority of farmers in Nhambita.

If the production of jatropha grain and PPO exceed the absorption capacity of the local market for lighting and soap, the more ambitious third scenario could be explored. However, it requires large amounts of land and labour to produce sufficient quantities of PPO. However, the scenario of replacing 50% of the diesel with PPO could initially also start by replacing 5% or 10%. Most likely, a higher capacity oil-press and storage capacity are needed to ensure year-round availability of PPO, as well as investments in the conversion of engines. Nevertheless, this scenario could provide guaranteed off-take of jatropha grain and thus reduce uncertainty and risks for smallholders producing jatropha. It would also lead to large quantities of organic fertilizer that could increase agricultural productivity in the area.

One may argue that many other scenarios could be included. The literature describes the use of jatropha oil for cooking, jatropha oil extracts as insecticide or fungicide, or using press-cake as animal fodder (cf. Jongschaap et al., 2007; de Jongh, 2010; FAO, 2010). On the assumption that 5.11 kg jatropha grain is needed to produce 1 l PPO, it is likely that the energy content in the remaining press-cake is actually higher than in the PPO itself. In that case, biogas production from the press-cake is an attractive option that adds extra value to the crop. On many of these applications, further research is needed.

7. Political and legal developments

The jatropha trials in Nhambita initially received considerable attention from high-level politicians and the media, who described the project as the first successful jatropha plantation in Mozambique, highlighting the potential for community-based biofuel production and use. Subsequently, the Ministry of Energy provided Envirotrade with an oil-seed press to produce PPO. Jatropha was presented in the NBPS as an "officially approved biofuel feedstock," that has: "[T]he firm commitment of the high-level leadership of national policy, on behalf of His Excellency, the President of the Republic of Mozambique, who has personally launched the campaign for *Jatropha curcas* farming in the country, one of the main raw materials for biodiesel production" (Government of Mozambique, 2009, p. 14).

Since then, much has changed. Scepticism about jatropha as a competitive biofuel feedstock has been growing in Mozambique and elsewhere. Crop failure due to the lack of agronomic knowledge about crop management, pests and diseases, and low productivity on the so-called marginal soils have tempered the initial enthusiasm about jatropha. Moreover, uncertainty about the GHG- and energy balance of jatropha biofuels, potential competition with food crop production and the bankruptcy of several jatropha plantations in Mozambique has reduced political interest in promoting jatropha. On the other hand, the Mozambican government is showing an interest in gathering lessons learned and using them to further operationalize and implement the country's NBPS.

Following international discussions on the sustainability of biofuels, the Mozambican government defined the necessary steps to develop a national biofuel sustainability framework. In 2010, Version 1 of the framework – including biofuel sustainability principles and criteria, and a guide for implementation – has been presented and discussed during stakeholder consultation workshops in Maputo, Nampula and Beira. The proposed framework has been designed to be integrated in the government's Project Application and Land Acquisition Process (Circular No. 009/DNTF/07),[11] which exempts smallholder biofuel producers or community-based projects from having to demonstrate compliance with the criteria. Moreover, the framework proposes incentive structures that could stimulate collaboration between commercial biofuel operators and smallholders producers, e.g. by stimulating technology transfer and knowledge sharing to enhance productivity. However, if smallholders produce for commercial biofuel operators (e.g. as outgrowers), compliance with the sustainability criteria is required. In the case of Nhambita, this could be problematic as the community is located in the buffer zone of Gorongosa NP, and one of the criteria specifically mentions that biofuel production shall avoid negative impacts on biodiversity, ecosystem functions and services, and land with high conservation value.

Government regulation for biofuel licensing is currently being developed. One of the proposed thresholds for requiring a government licence is the annual amount of biofuels produced. At the moment, this threshold is established at 5000 $l\,yr^{-1}$, which would mean that a biofuel licence would be required only in the case of the third scenario (Table 4). A possible advantage is that the regulation proposes that biofuels produced by smallholder cooperatives or association are exempt from paying taxes.

Another interesting development is the attempt to receive carbon credits for planting jatropha. Several projects are exploring this opportunity. If such an attempt was successful, it could provide an incentive for Envirotrade to include jatropha production as one of the agro-forestry contracts where farmers receive payments for carbon conservation.

8. Analysis and discussion

The objective of this paper was to provide insights into the opportunities and constrains that influence the innovation space for sustainable community-based production and processing of biofuel feedstock for localized use or for local marketing. Although we consider this paper to be exploratory in nature and we could not fully grasp the complexity of, e.g. resource allocation in the community and biophysical conditions for growing jatropha, it does provide a starting point for more systematic and strategic thinking about community-based biofuel production and use. Moreover, lessons learned from existing community-based jatropha projects (in Mozambique and other SSA countries) are scarce but essential to sensitize policymakers and other stakeholders on the complexities of community-based biofuel production and use. In the following sections, we further analyse and discuss our data, focusing on demonstrating how the dynamics and interactions between social–cultural, biophysical, economic, political and legal subsystems across different scales and levels of analysis through time influence the space for innovation for community-based biofuel production and use.

8.1. Integrated assessment of subsystems that constitute space for innovation

Although our analysis of biophysical conditions was not supported by e.g. laboratory analysis of soil samples, it seems that factors such as temperature, soil quality and fertility status, and water availability do not make jatropha production in the area impossible. Mean rainfall in the region (850 $mm\,yr^{-1}$) and its distribution (82% of the rain falls in five months) does not create optimal growing conditions for jatropha production, although the crop is known to produce grain

[11] This procedure links the processes for awarding land titles and approving investment proposals of large-scale commercial agricultural projects (Schut et al., 2010c, p. 5154).

with a minimum water availability of 500–600 mm yr^{-1} (Euler and Gorriz, 2004). Data from South Africa underline the production potential of jatropha under dry conditions, as non-irrigated, unfertilized 4-year-old jatropha (741 trees ha^{-1}) yielded 1286 kg dry grain ha^{-1} in a growing season of 8.5 months with 652 mm rainfall (Jongschaap et al., 2009). Furthermore, data from interviews and observations in relation to the successful first growing season of the trials, the good condition of jatropha on the *machamba* of the high resource endowed farm in September 2009 and the fact that jatropha in the communal trial died after the first pruning make us conclude that there is acceptable biophysical space to produce jatropha in Nhambita community. Pest, disease and crop management in general seem to have hampered the production potential of jatropha in the community.

The analysis of the economic space demonstrated the potential for local use and marketing of biofuels and other applications of PPO. The majority of households buy petroleum for lighting, and one of the main expenditures of households is soap purchase. Moreover, the Envirotrade project uses large quantities of diesel that could partly be replaced by PPO. Within all scenarios, organic fertilizer can be produced, which could increase agricultural productivity as currently only a very small percentage of farmers apply fertilizer. The high added value of jatropha when processed and used locally may allow for higher jatropha grain prices for farmers compared with selling unprocessed jatropha grain for a market price of US$0.11 kg^{-1}. Moreover, supplying the local market is less sensitive to outside distortions such as highly fluctuating fossil fuel prices. Whether estimated grain yields (1250 kg ha^{-1} yr^{-1}) are realistic and allow for competitive production as compared with producing other cash crops, Envirotrade's agro-forestry contracts or allocating labour to off-farm activities requires further research.

How the performance of a crop, and political and legal space can be interrelated is nicely demonstrated in the Nhambita case. Initially, the project received considerable attention from politicians, and the project was used to underline the government's political commitment to the emerging biofuel sector and the potential for biofuel – and more specifically jatropha – production in Mozambique. On the basis of the initial success of projects like Nhambita, jatropha was officially approved by the government as biofuel feedstock, and this created the legal basis for the expansion of commercial and community-based jatropha production in Mozambique. However, discussions on competition between biofuel and food production, crop failure and growing criticism of jatropha as a 'miracle crop' have reduced the political space for jatropha in Mozambique. Government officials have acknowledged that the initial promotion of jatropha was mainly based on wishful thinking, lacking profound analysis and a clear strategy. There is a willingness to learn from existing experiences however, and to use these experiences in developing and implementing more realistic and sustainable biofuel policies.

Despite the potential biophysical and economic space for community-based biofuel production and use, the initial political commitment and legal space for jatropha production in Mozambique, our study has demonstrated that different farm households have different reasons for allocating or not allocating resources to producing jatropha. We must conclude that farmers are not reluctant to adopt agricultural innovations. The success of pigeonpea cultivation in Nhambita shows that the introduction of new (cash) crops can be sustainable if some critical conditions are met. Farmers carefully allocate their labour and land to crops and activities that provide resilience in terms of meeting their demands for food and income. Our data show that labour availability, its allocation and labour synergies at the community level are crucial for understanding these trade-offs at farm level. The low resource endowed household faces multiple constraints in terms of achieving food self-sufficiency given their current household and farm size, and the amount of labour they can invest in the own farm. The risks associated with allocating resources to a single-purpose, non-food crop such as jatropha, of which they have little knowledge and that only gives profitable yields after three to four years, are too high under the current conditions. High and medium resource endowed households have land and labour available, and – in the case of the high resource endowed farm – experience some sort of space to experiment. Nevertheless, our data demonstrate that also the high resource endowed household decided to allocate available resources (in this case labour) to activities other than producing jatropha. The main reason for this can be found in a lack of trust in the crop, driven by the failure of the communal jatropha trials, lack of agronomic knowledge about the crop, and the absence of organized markets and supply chains.

Our data demonstrate the complex dynamics of community-based biofuel production and use, and how interactions between different subsystems influence the extent to which an agricultural innovation (such as jatropha or another biofuel crop) can contribute to sustainable development. Especially in the case of community-based biofuel production and use, understand the context-specific multiple realities of smallholder farming and its synergies at community level is crucial, as it is the farmers who eventually determine whether community-based biofuel production and use is perceived as an opportunity or a threat.

8.2. Spatial and temporal dynamics that influence space for innovation

In the previous section, we addressed some of the interactions between scales and levels of analysis e.g. how trade-offs at farm level influence labour dynamics at community level, and how changes in political or legal space at the national level affect local space for innovation. Another example can be found in the proposed Mozambican biofuel sustainability framework, which includes criteria that seek to avoid biofuel production and processing near nature conservation areas and areas that are highly biodiverse. If implemented, this criterion would affect the possibility for farmers from Nhambita (being located in the buffer zone of Gorongosa NP) to work as outgrowers, producing jatropha grain for a commercial biofuel operator. As the development of the biofuel sustainability framework emerged from international debates on the sustainability of biofuels, this illustrates how dynamics across different scales and levels affect the local space for innovation. On the other hand, the Mozambican biofuel sustainability framework also provides opportunities for smallholder communities, as it includes criteria that promote collaboration between commercial and smallholder biofuel producers in terms of knowledge and technology transfer to enhance agricultural productivity.

Depending on the volume of biofuel production, a government licence might be required. Studies have shown that smallholders or smallholder communities often lack the financial, administrative and organizational capacity to meet such requirements (Schut et al., 2010a). This underlines the need for adequate support mechanisms that can create an enabling environment for community-based biofuel projects, rather than create additional obstacles. A good example of how a legal space at the national level can enhance local space for innovation is the government's intention to integrate the biofuel sustainability criteria in the existing Project Application and Land Acquisition Process, which exempts smallholder biofuel producers from having to demonstrate compliance with the biofuel sustainability criteria if the biofuels are produced, processed and used locally.

The Nhambita case provides some clear examples of how space for innovation changes through time. Initially, the prospects for biofuel production and use in Nhambita community were promising. Envirotrade supported the development of jatropha trials, the jatropha was growing well, an influential farmer planted jatropha on his *machamba*, farmers from the area expressed an interest in growing jatropha and an oil-seed press was provided to the community. However, the lack of agronomic knowledge about crop management eventually heralded the failure of jatropha in the community, and farmers lost their trust in the crop. Furthermore, the disappointing results of community-based and commercial jatropha projects have reduced political interest in promoting jatropha. However, the analysis of these (mainly disappointing) experiences may contribute to more realistic prospects for jatropha biofuels in Mozambique and other SSA countries. Recent studies have created widespread awareness that the performance of jatropha – like any other crop – depends on specific biophysical conditions such as nutrient and water availability, and adequate crop management. The sharing of research data and experiences with regard to crop management, harvesting, seed and grain storage, oil pressing, using PPO for domestic lighting, local production of soap, but also project and social organization, is essential for the development of policy that provides a more enabling environment for existing and future community-based biofuel projects. Although it is unlikely that farmers' trust in jatropha can easily be restored in Nhambita community, the case provides an incentive for more strategic thinking in the design and implementation of biofuel policy, and for the development of adaptive capacity in policy to respond to the uncertainties of community-based biofuel production and use in Mozambique (cf. Verdonk et al., 2007).

9. Conclusions and recommendations for policy

This study shows that the design and implementation of biofuel policy concerned with sustainable community-based biofuel production and use requires integrated assessment of social–cultural, biophysical, economic, political and legal subsystems within which innovations like jatropha are expected to contribute to sustainable and dynamic rural development. Moreover, interactions across different scales and levels of analysis (farm level, community level, country level, as well as internationally) and temporal dynamics influence the extent to which local space for innovation for community-based biofuel production and use can be created and sustained.

The way jatropha production in Nhambita was promoted by the Mozambican government caused disappointing results that have negatively affected farmers' trust in the biofuel crop. Agricultural innovations, such as the introduction of biofuel crops in smallholder farming systems, are unsuitable for 'silver bullet' solutions or linear trajectories (Giller et al., 2011; van Mierlo et al., 2011). It implies that community-based biofuel policies must be targeted to the specific context in which farming takes place, taking into account the complexity of different farming strategies and their synergies at community level. This makes the design and implementation of biofuel policies concerned with community-based biofuel production and use fundamentally different from other rural energy policies. It does not mean that no policy strategies can be developed however. There exist *ex-ante* integrated assessment tools (see e.g. the NUANCES-framework—http://www.africanuances.nl) that can contribute to more strategic policy development regarding agricultural innovations and interventions, before they are promoted amongst smallholder farmers (Giller et al., 2011).

Moreover, policies that promote community-based biofuel production and use should focus on creating an enabling environment. Such an environment should provide safe space for experimentation and institutional support in terms of capacity building, sharing knowledge and experiences, and market development. An enabling environment could enhance local space for innovation by continuously adapting to local demands and the changing context in which biofuel developments take place, preventing biofuels from becoming a threat rather than an opportunity for smallholders (Verdonk et al., 2007). Envirotrade has several mechanisms in place that could support community-based biofuel production and use. Examples include the annual remuneration for planting and maintaining trees that reduces risks and results in short-term, financial benefits for smallholders. Furthermore, the microbusiness associations and rural community committees and trust funds could facilitate the social organization of community-based biofuel activities, as well as the distribution of benefits.

Acknowledgements

The authors thank the Mozambican Ministry of Energy, National Directorate for Renewable Energy (DNER) and GTZ-ProBEC for supporting this research. This study contributes to the strategic research programme 'Sustainable spatial development of ecosystems, landscapes, seas and regions,' funded by the Dutch Ministry of Economic Affairs, Agriculture and Innovation (former Ministry of Agriculture, Nature Conservation and Food Quality). The research also formed part of the Competing Claims—Competing Models programme jointly funded by Wageningen University and Research Centre and the Dutch Ministry of Foreign Affairs (DGIS).

We express our gratitude to the Envirotrade project staff for facilitating our stay in Nhambita community. We are grateful to Nhambita community for welcoming us and giving us permission to do our fieldwork. The authors acknowledge the valuable contributions of colleagues, especially Raymond Jongschaap, Shamie Zingore, Flemming Nielsen and Ken Giller, and the journal's anonymous reviewer who provided constructive feedback on earlier versions of this paper.

References

Agyare, W.A., Kombiok, J.M., Karbo, N., Larbi, A., 2002. Management of pigeon pea in short fallows for crop-livestock production systems in the Guinea savanna zone of northern Ghana. Agroforestry Systems 54, 197–202.
Arthur, M., de Fatima, S.R., Zahran, S., Bucini, G., 2010. On the adoption of electricity as a domestic source by Mozambican households. Energy Policy 38, 7235–7249.
Batidzirai, B., Faaij, A.P.C., Smeets, E., 2006. Biomass and bioenergy supply from Mozambique. Energy for Sustainable Development X, 54–81.
Bos, S., Leonardo, W., Lerner, A., Schut, M., 2010. Assessing the Potential of Bioenergy Production in Smallholder Farming Systems: The Case of Nhambita Community. GTZ-ProBEC and Wageningen University and Research Centre, Maputo (p. 47).
Campbell, B., Frost, P., Byron, N., 1996. Miombo woodlands and their use: overview and key issues. In: Campbell, B. (Ed.), The Miombo in Transition: Woodlands and Welfare in Africa. Center for International Forestry Research (CIFOR), Bogor, Indonesia, pp. 1–10.
Cash, D.W., Adger, W.N., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., Young, O., 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. Ecology and Society, 11.
Coughlin, P.E., 2006. Agricultural Intensification in Mozambique: Infrastructure, Policy and Institutional Framework. EconPolicy Research Group, Lda. (p. 78).
de Jongh, J. (Ed.), 2010. The Jatropha Handbook, From Cultivation to Application. FACT Foundation, Eindhoven.
Envirotrade, 2006. Annual Report 2006—Plan Vivo. Envirotrade Ltd. (p. 27).
Euler, H., Gorriz, D., 2004. Case study "*Jatropha curcas*". Global Facilitation Unit for Underutilized Species (GFU) and GTZ, Frankfurt, Germany (p. 63).
FAO, 2010. Jatropha: A Smallholder Bioenergy Crop. The Potential for Pro-Poor Development. IFAD and FAO, Rome (p. 96).
FAO/WFP, 2010. Special Report: FAO/WFP Crop and Food Security Assessment Mission to Mozambique. Food and Agriculture Organization (FAO) and World Food Programme (WFP), Rome (p. 36).
Frost, P., 1996. The ecology of Miombo woodlands. In: Campbell, B. (Ed.), The Miombo in Transition: Woodlands and Welfare in Africa. Center for International Forestry Research (CIFOR), Bogor, Indonesia, pp. 11–55.
Giller, K.E., 2001. Nitrogen Fixation in Tropical Cropping Systems second ed CAB International, Wallingford.
Giller, K.E., Leeuwis, C., Andersson, J.A., Andriesse, W., Brouwer, A., Frost, P., Hebinck, P., Heitkönig, I., van Ittersum, M.K., Koning, N., van Wijk, M.T., Windmeijer, P., 2008. Competing claims on natural resources: what role for science? Ecology and Society 13, 18.

Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'Ungu, J., Mwale, M., Nwaga, D., Pacini, C., Vanlauwe, B., 2011. Communicating complexity: integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104, 191–203.

Government of Mozambique, 2009. Política e Estratégia de Biocombustíveis—Resolução 22/2009. Government of Mozambique, Maputo (p. 9).

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technological Forecasting and Social Change 74, 413–432.

Howard, J., Crawford, E., Kelly, V., Demeke, M., Jeje, J.J., 2003. Promoting high-input maize technologies in Africa: the Sasakawa-Global 2000 experience in Ethiopia and Mozambique. Food Policy 28, 335–348.

Jongschaap, R.E.E., Corré, W.J., Bindraban, P.S., Brandenburg, W.A., 2007. Claims and facts on *Jatropha curcas* L.: global *Jatropha curcas* evaluation. breeding and propagation programme, Report/Plant Research International; 158. Plant Research International, Wageningen.

Jongschaap, R.E.E., Blesgraaf, R.A.R., Bogaard, T.A., van Loo, E.N., Savenije, H.G., 2009. The water footprint of bioenergy from *Jatropha curcas* L. Proceedings of the National Academy of Sciences 106, E92.

Jumbe, C.B.L., Msiska, F.B.M., Madjera, M., 2009. Biofuels development in Sub-Saharan Africa: are the policies conducive? Energy Policy 37, 4980–4986.

Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agricultural Systems. 103, 390–400.

Leeuwis, C., Aarts, N., 2011. Rethinking communication in innovation processes: creating space for change in complex systems. The Journal of Agricultural Education and Extension 17, 21–36.

Mangoyana, R.B., Smith, T.F., 2011. Decentralised bioenergy systems: a review of opportunities and threats. Energy Policy 39, 1286–1295.

Mather, D., Cunguara, B., Boughton, D., 2008. Household Income and Assets in Rural Mozambique, 2002–2005: Can Pro-poor Growth be Sustained?. Ministry of Agriculture, Directorate of Economics, Government of Mozambique (p. 80).

Practical Action Consulting, 2009. Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Prepared for Pisces and FAO by Practical Action Consulting, Rome, p. 134.

Russell Bernard, H., 2006. Research Methods in Anthropology. Qualitative and Quantitative Approaches fourth ed AltaMira Press.

Ryan, C.M., 2009. Carbon Cycling, Fire and Phenology in a Tropical Savanna Woodland in Nhambita, Mozambique. University of Edinburgh, Edinburgh.

Schut, M., Bos, S., Machuama, L., Slingerland, M., 2010a. Working Towards Sustainability. Learning Experiences for Sustainable Biofuel Strategies in Mozambique. Wageningen University and Research Centre, Wageningen, The Netherlands in Collaboration with Cepagri, Maputo, Mozambique (p. 103).

Schut, M., Leeuwis, C., van Paassen, A., 2010b. Room for the River—room for research? The case of depoldering De Noordwaard, the Netherlands. Science and Public Policy 37, 611–627.

Schut, M., Slingerland, M., Locke, A., 2010c. Biofuel developments in Mozambique. Update and analysis of policy, potential and reality. Energy Policy 38, 5151–5165.

Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. International Journal of Foresight and Innovation Policy 2004, 4–32.

Tittonell, P., van Wijk, M.T., Herrero, M., Rufino, M.C., de Ridder, N., Giller, K.E., 2009. Beyond resource constraints—exploring the biophysical feasibility of options for the intensification of smallholder crop-livestock systems in Vihiga district, Kenya. Agricultural Systems 101, 1–19.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., Giller, K.E., 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya, I: heterogeneity at region and farm scale. Agriculture, Ecosystems & Environment 110, 149–165.

Tschirley, D.L., Weber, M.T., 1994. Food security strategies under extremely adverse conditions: The determinants of household income and consumption in rural Mozambique. World Development 22, 159–173.

University of Edinburgh, 2008. Miombo Community Land Use & Carbon Management Nhambita Pilot Project. The University of Edinburgh, School of Geo-Sciences (pp. 52–194).

van Eijck, J., Romijn, H., 2008. Prospects for Jatropha biofuels in Tanzania: an analysis with Strategic Niche Management. Energy Policy 36, 311–325.

van Mierlo, B., Arkesteijn, M., Leeuwis, C., 2010. Enhancing the reflexivity of system innovation projects with system analyses. American Journal of Evaluation 31, 143–161.

van Wijk, M.T., Tittonell, P., Rufino, M.C., Herrero, M., Pacini, C., Ridder, N.d., Giller, K.E., 2009. Identifying key entry-points for strategic management of smallholder farming systems in sub-Saharan Africa using the dynamic farm-scale simulation model NUANCES-FARMSIM. Agricultural Systems 102, 89–101.

Verdonk, M., Dieperink, C., Faaij, A.P.C., 2007. Governance of the emerging bio-energy markets. Energy Policy 35, 3909–3924.

Zingore, S., Murwira, H.K., Delve, R.J., Giller, K.E., 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture, Ecosystems & Environment 119, 112–126.

Zingore, S., González-Estrada, E., Delve, R.J., Herrero, M., Dimes, J.P., Giller, K.E., 2009. An integrated evaluation of strategies for enhancing productivity and profitability of resource-constrained smallholder farms in Zimbabwe. Agricultural Systems 101 (2009), 57–68.

Zingore, S., Tittonell, P., Corbeels, M., van Wijk, M., Giller, K.E., 2011. Managing soil fertility diversity to enhance resource use efficiencies in smallholder farming systems: a case from Murewa District, Zimbabwe. Nutrient Cycling in Agroecosystems 90, 87–103.